Adaptation of engineering design methods for multidisciplinary development processes considering heterogeneous teams

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Für meine Familie

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ABSTRACT

Due to the increasing globalisation as well as digitalisation of the working environment and the enhanced complexity of today's products, engineering design teams are no longer working together locally but increasingly across sites, disciplines and country borders. Especially in these circumstances, a systematic approach as well as the use of engineering design methods can support the teams in their collaboration. Current method provision approaches, e.g. method descriptions in a book, typically address local collaborative teams and contain little to no evidence of appropriate team composition or required characteristics of the team (e.g. multidisciplinarity or local distribution of the team) for a successful method application. Therefore, the aim of this thesis is the development of a team-oriented method provision concept, which regards the consideration of method user characteristics in method descriptions and access. For this purpose, existing method provision approaches with regard to describing and accessing attributes are analysed. Particular attention is paid to team- and user-oriented attributes. Enriched with the results of a study in six enterprises regarding their needs, requirements for a team-oriented method provision are derived. In addition, a sensitivity analysis is carried out, which shows the relevance of method user characteristics in relation to the application of selected methods. The results are gathered in an impact model. Together with the requirements on method provision, a concept for team-oriented method provision is developed. It consists of an assessment tool for method user characteristics, a method description model, and a corresponding method access algorithm. Parallel to the provision, existing training concepts for methods in education and practice are examined. Success factors and barriers are deduced from these concepts, subsequently. Based on these, suitable training concepts are designed for the two target groups education and practice. The training concepts include the team-oriented method provision concept in the form of a software demonstrator. These training concepts and the team-oriented method provision tool are tested and evaluated both in education and practice. The results show a positive acceptance of the tool by both students and engineers in practice.

Kurzfassung

Durch die zunehmende Globalisierung und Digitalisierung der Arbeitswelt sowie einen Anstieg der Produktkomplexität arbeiten Entwicklungsteams nicht länger nur lokal zusammen, sondern vermehrt über Disziplinen, Standorte und Ländergrenzen hinweg. Vor allem unter diesen Bedingungen können das methodische Vorgehen sowie der Einsatz von Produktentwicklungsmethoden die Teams bei ihrer Zusammenarbeit unterstützen. Aktuelle Methodenbereitstellungskonzepte, z. B. innerhalb Methodenbeschreibungen in Büchern, adressieren in der Regel lokal zusammenarbeitende Teams und enthalten keine bis wenige Hinweise auf eine geeignete Teamzusammensetzung oder erforderliche Eigenschaften des Teams (wie die Multidisziplinarität oder örtliche Verteilung des Teams) für eine erfolgreiche Methodenanwendung. Ziel dieser Arbeit ist daher die Entwicklung eines teamorientierten Bereitstellungskonzeptes für Methodenbeschreibung und -auswahl unter Berücksichtigung von Teameigenschaften. Hierzu werden bestehende Ansätze hinsichtlich ihrer Beschreibungs- und Zugriffsattribute analysiert. Besonderes Augenmerk liegt dabei auf Attributen bezüglich des Methodenanwenders und des Teams Angereichert um Ergebnisse einer Studie in Unternehmen hinsichtlich ihrer Bedarfe werden Anforderungen an eine teamorientierte Methodenbereitstellung abgeleitet. Ergänzend wird eine Sensitivitätsanalyse durchgeführt, die die Relevanz von Teameigenschaften in Bezug auf die Anwendung ausgewählter Methoden aufzeigt. Die Ergebnisse werden in einem Einflussmodell aufbereitet und zusammen mit den Anforderungen an die Methodenbereitstellung genutzt, um ein Konzept für eine teamorientierte Methodenbereitstellung zu entwickeln. Diese besteht aus einem Erfassungstool für Teameigenschaften, einem Methodenbeschreibungsmodell sowie einen Zugriffsalgorithmus. Parallel zur Bereitstellung werden bestehende Schulungsmöglichkeiten für Methoden in Industrie und Lehre untersucht und Erfolgsfaktoren sowie Barrieren abgeleitet. Darauf basierend werden zu den Zielgruppen Industrie und Lehre passende Schulungskonzepte konzipiert, die eine Einbindung der teamorientierten Methodenbereitstellung in Form eines Softwaredemonstrators vorsehen. Diese Schulungskonzepte sowie das teamorientierte Methodenbereitstellungstool werden sowohl in der Lehre als auch in der Industrie getestet und evaluiert. Die Ergebnisse

zeigen eine positive Aufnahme des Tools sowohl bei den Studierenden als auch bei Ingenieuren in der Praxis.

Contents

1 Introduction 1

1.1 Initial situation and problem statement 1

1.2 Aims and scientific approach 4

1.2.1 Research goals 5

1.2.2 Research questions 6

1.2.3 Research methodology 7

1.3 Thesis structure 10

2 State of the Art 13

2.1 Design methodology 14

2.1.1 Development process in engineering design 14

2.1.2 Engineering design methods 19

2.1.3 Provision of design methods 25

2.2 Design organisation 30

2.2.1 Engineering design teams 31

2.2.2 Virtual teams in locally distributed environments 41

2.3 Knowledge transfer and training in design education and practice 51

2.3.1 Introduction to knowledge transfer 52

2.3.2 General didactical concepts 54

2.3.3 Method knowledge transfer and training 63

2.4 Summary of the state of the art 67

3 Problem Clarification 69

3.1 Refinement of the research gap 69

3.2 Intended results 72

4 Analysis of Method Provision Approaches 75

4.1 Terms and definitions 76

4.2 Literature-based analysis of method provision approaches 81

4.2.1 Preprocessing of analysing method provision approaches 81

4.2.2 Analysis of method descriptions 95
4.2.3 Analysis of method access 103
4.3 Method provision in practice 108
4.4 Resulting requirements on method provision 111
4.4.1 Conclusion from the literature-based analysis 112
4.4.2 Conclusion of practical survey 113
4.4.3 Resulting requirements for team-oriented method provision 115
4.5 Reflection on research questions 117

5 ANALYSIS OF TRAINING APPROACHES FOR DESIGN METHODS 119

5.1 Terms and definitions 120
5.2 Identification of requirements on method knowledge transfer 121
5.2.1 Analysis of success factors and barriers for method knowledge transfer 121
5.2.2 Analysis of existing method training concepts 123
5.2.3 Analysis of formats and media for method knowledge transfer 125
5.3 Resulting requirements for method training in design education and practice 128
5.4 Reflection on research question 129

6 DEVELOPMENT OF A METHOD PROVISION TOOL FOR TEAMS 131

6.1 Extension of current method provision approaches 132
6.1.1 Deduction of method user characteristics for method provision 132
6.1.2 Sensitivity analysis of relevant team-oriented attributes 138
6.1.3 Impact model and resulting requirements on method provision 141
6.2 Concept for a method provision tool for teams 142
6.2.1 An assessment tool for determining method user characteristics 143
6.2.2 A team-oriented method description model 150
6.2.3 A concept for method access considering method user characteristics 154
6.2.4 Interim conclusion 159
6.2.5 Exemplary scenarios 160
6.3 The method portal METHODOS as a software demonstrator 166
6.3.1 METHODOS as method provision tool for teams 166
6.3.2 Method descriptions in METHODOS 167

6.3.3 Method access in METHODOS 170
6.4 Reflection on research questions 171

7 DEVELOPMENT OF CONCEPTS FOR TRAINING DESIGN METHODS 173

7.1 General didactic method training media and formats 174
7.1.1 Method videos 174
7.1.2 Instructions for methods 176
7.1.3 Software tools and templates 177
7.2 Concepts for design education 180
7.2.1 Integration of the method provision tool into classroom-based courses 181
7.2.2 Integration of the method provision tool into an online course 183
7.3 A concept for training design methods in practice 184
7.3.1 Workshop on design methods in practice 187
7.3.2 Online workshop for virtual teams 188
7.4 Conclusion and reflection on research question 190

8 EVALUATION STUDIES 193

8.1 General evaluation 193
8.1.1 Evaluation of the method provision tool's usability 194
8.1.2 Evaluation of method training media 197
8.2 Evaluation in design education 199
8.2.1 Realisation 200
8.2.2 Results on method provision 201
8.2.3 Results on the concept for training design methods 204
8.3 Evaluation in practice 207
8.3.1 Local team workshop 207
8.3.2 Virtual team workshop 214
8.4 Comparison of design education and practice 216
8.4.1 Results on method provision 216
8.4.2 Results on training concepts 219
8.5 Discussion of the results 220

9 CONCLUSION AND OUTLOOK 223

9.1 Summary of research results 223
9.2 Reflection of research results 225
9.3 Outlook and future work 228

REFERENCES 231

GLOSSARY 247

APPENDICES 249

LIST OF PUBLICATIONS 279

BERICHTE AUS DEM INSTITUT 281

Abbreviations

Ø	average
A	assumption
ARC	areas of relevance and contribution
BEMAP	Behavioral Marker in der Produktentwicklung (in product development)
BTRSPI	Belbin's Team-Role Self-Perception Inventory
CFD	Computational Fluid Dynamics
CI	confidence interval
C.R.I.	Competence-Reflection-Inventory
CSCW	computer-supported collaborative work
DE	design education
DG-MOTS	Design Game Matrix of Tool Selection
DRM	Design Research Methodology
DS I	descriptive study I
DS II	descriptive study II
E	essential (priority of requirements)
ERDF	European Regional Development Fund
EXE	executable
FMEA	Failure Mode and Effect Analysis
GINA	Holistic Innovation Processes in Modular Enterprise Networks
GPK	Grundlagen der Produktentwicklung und Konstruktion (basics of product development and engineering design)
IK	Institut für Konstruktionstechnik (Institute for Engineering Design)
iPeM	integriertes Produktentstehungsmodell (integrated Product engineering Model)
IPO	input process output
IPPOP	Integration of Product, Process and Organization for Engineering Performance Improvement
ISO	International Organization for Standardization
KaLeP	Karlsruher Lehrmodell für Produktentwicklung (Karlsruhe Education Model for Product Development)
KIT	Karlsruhe Institute of Technology
KSA(O)	knowledge, skills, abilities (and other characteristics)
LDAP	Lightweight Directory Access Protocol
LSI	Learning Style Inventory
M	mean

M	minimum (priority of requirements)
MIT	Massachusetts Institute of Technology
MOOC	Massive Open Online Course
m.p.t.	method provision tool
MuPro-KMU	Methodische Unterstützung der Produktentwicklung in kleinen und mittleren Unternehmen (methodical support for engineering design in SME)
n	sample size
NMP	Neue Methoden der Produktentwicklung (new methods of product development)
No.	number
O	optional (priority of requirements)
OEM	original equipment manufacturer
OW	online workshop
P	practice
PDF	Portable Document Format
PoMM	Process-oriented Method Model
PS	prescriptive study
Q	question
QFD	Quality Function Deployment
RC	research clarification
SAM model	Modell des situationsangepassten Methodeneinsatzes (model for the use of methods adapted to the situation)
SD	standard deviation
SME	small and medium-sized enterprises
TOTE	Test Operate Test Exit
TRIZ	the theory of inventive problem solving
TU	Technische Universität / Technical University
VARK	visual, aural, read/write and kinaesthetic
VBA	Visual Basics for Application
VDI	Verein Deutscher Ingenieure (The Association of German Engineers)
VICO	virtual qualification coach
VR	virtual reality
VTCI	Virtual Team Competency Inventory
WS	workshop

1 INTRODUCTION

"Knowing is not enough; we must apply.
Willing is not enough; we must do."
Johann Wolfgang von Goethe, German poet

Following the quotation from Goethe, the focus of the thesis at hand is on how to transfer knowledge of engineering design methods to students and practitioners to enable them to apply the methods. A central aspect of this research work is the significance of the engineering designer as an important element for a successful product development. The increasing importance of this consideration will be explained subsequently.

1.1 Initial situation and problem statement

More and more complex systems and increased time pressure due to shorter product life cycles demand collaborations across company boundaries as well as focussing on core know-how from many companies. This leads to the creation of value networks that develop products cooperatively. Generally, the partners in such value networks are located at regionally or even internationally distributed sites. The local distribution oftentimes results in at least partially virtual collaboration which is enabled by the increasing digitalisation of the working environment (Dulebohn & Hoch, 2017; Kauffeld et al., 2016). In this thesis, virtual teamwork is based on the understanding of Schumacher (2011). It is the collaboration of several people in different localities pursuing a common goal: the development task. Consequently, a challenge is to find ways that allow collaboration through an exchange of information. Further challenges arise from time differences over several time zones. Time shifts hinder an easy instantaneous communication, meaning communication at the same time. Another challenge of collaboration originates from the involvement of various disciplines, like mechanics, electronics or software, due to sometimes strong specialization of each partner. Because of the above-mentioned challenges, virtual and multidisciplinary teamwork usually requires more competencies from the partners than traditional face-to-face teamwork (Hertel et al., 2006; Kauffeld et al., 2016; Schulze & Krumm, 2017). For example, methodological competencies for dealing with new technologies for virtual collaboration or communication are necessary. In addition, knowledge about appropriate methods, systematic approaches and also a methodological competence can foster collaboration. In this connection, the collaborators can choose from a variety of different engineering design methods. These methods are described and accessible in databases or in literature, e.g. Lindemann (2009), TIM (2013). Despite the number of methods available, former literature, e.g. Jänsch (2007), and surveys among engineers from industry, e.g. Schneider et al. (2006), show only a low acceptance and application of methods. The study MuPro-KMU[1], for instance, was conducted among 90 participants from five small and medium-sized enterprises (SMEs) and one large enterprise in the region of Lower Saxony, Germany (Bavendiek et al., 2014). The results show that approximately half of the 20 design methods requested are known, such as Brainstorming, Gallery Method or Quality Function Deployment (QFD) or Synectics. Only 20 % of these methods, including Brainstorming, the Requirement List, checklists and Failure Mode and Effects Analysis (FMEA), are used. The respondents also indicated that the small number of used methods are often not used very regularly but rather infrequently. The main purpose of a method application in practice, referring to the survey results, are ideation and evaluation as well as decision-making (Bavendiek et al., 2014; Vietor, 2015). Similar results can be found in previous or parallel research such as Albers et al. (2014), Geis, Bierhals et al. (2008) or Jänsch (2007).

Especially Araujo, JR (2001) and Jänsch (2007) deal with barriers that inhibit the application of methods and their acceptance in practice. Examples of these barriers are a lack of adaptability of methods, a theoretical overload or the "strange kind of language" (Araujo, JR, 2001) in method provision. Further barriers are an excessive amount of time in both application and training (Jänsch, 2007) as the methods are difficult to understand (Araujo, JR, 2001). These findings could be confirmed in the mentioned MuPro-KMU study for the region of Lower Saxony (Bavendiek et al., 2014). Thus, there is a gap between design research that provides a broad set of methods and practice where only a fraction of the methods are

[1] Details on the study MuPro-KMU will be given in Section 1.2.3 and can be found in Vietor (2015).

used (Wallace, 2011). So, one of the main assumptions of the underlying thesis is formulated as follows:

> **A1** The acceptance of applying engineering design methods is supported by a suitable method provision.

Taking into account the initial situation described above concerning the increasing distribution of development tasks and the resulting virtual as well as multidisciplinary collaboration, the consideration of the design team and its characteristics emerge when describing, accessing and also adapting methods. Current method descriptions usually contain little to no information about the needed qualification and requirements on the method user (Badke-Schaub et al., 2011). Beside the team size and the experience of the method user (Braun, 2005), there is generally no further information available about the team. An approach adapting methods to the experiences of the method user is proposed by Braun (2005). Any consideration of special constraints in virtual and multidisciplinary teams is missing though. The strong changes in the working environment due to virtual, multidisciplinary and dynamic team constellations demand adaptions of methods or at least hints for the method applicability among these new circumstances. Thus, methods should not be considered independently from its user or the team of users. This leads to the second main assumption:

> **A2** Method user characteristics influence the selection of a suitable method in engineering design.

Returning to the introductory quotation of Goethe, the formation and studies as an origin of knowledge play an important role. But knowledge alone is not enough; it has to be applied. This can be transferred to design education, especially focussing on engineering design methods. The above-cited MuPro-KMU study shows that much of the knowledge on methods originates from studies or formation (Bavendiek et al., 2014; Vietor, 2015), see Figure 1-1. The following conclusion is drawn from this finding: design method training at higher education institutions, like universities in the field of engineering design, has to be made more sustainable to establish the methods in practice in the long-term. According to

Goethe, a possible way is the intensified application of the method knowledge. However, it is not too late to intensify the method usage in practice as well to reduce the gap between research and practice. This can be achieved on the one hand by strengthening the method formation in design education. On the other hand suitable training concepts in practice, for instance, with workshops can promote the method application.

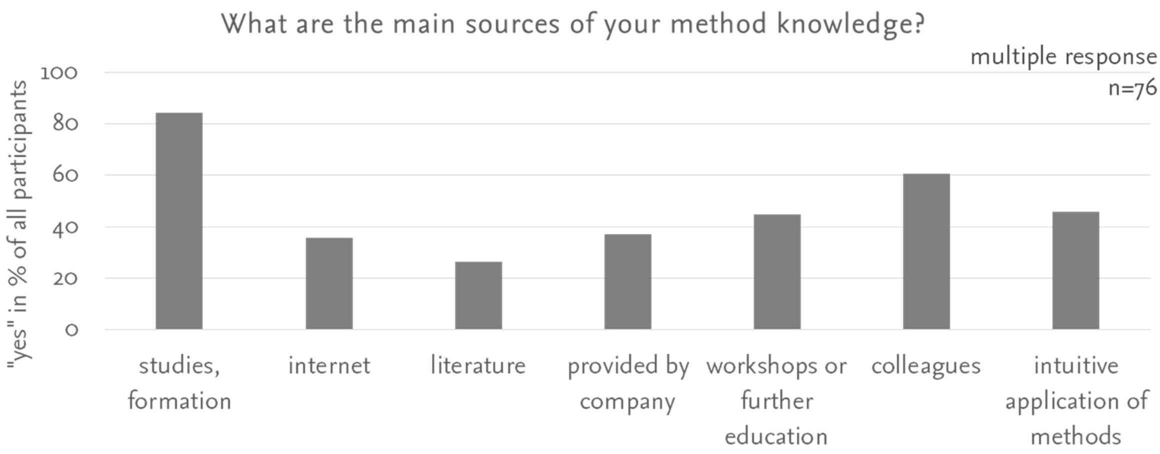


Figure 1-1 Results of the MuPro-KMU survey concerning the sources of method knowledge (based on Bavendiek et al., 2014)

Though, it has to be considered that students and practitioners hold different experience and knowledge conditions (Lenhart & Birkhofer, 2006). Thus, the level of experience is important when preparing training concepts and material (Lenhart & Birkhofer, 2007). The third and final main assumption of this research work is subsequently:

A3	To achieve a successful method knowledge transfer the target group has to be considered.

The three formulated assumptions will be used in the following to deduce the aim and the subsequent approach of this research work.

1.2 Aims and scientific approach

This section takes the three main assumptions up to establish the research goal and to refine the goal in terms of research questions. Due to the wide field of aspects influencing this research work, the definition of research questions helps to understand the focus on essential areas of research at the beginning of this thesis. These areas originate in different research disciplines being engineering design, psychology as well as didactics. To concentrate only on the relevant aspects of these wide areas, the subsequent sections narrow the research topic down using research questions.

1.2.1 Research goals

Based on the initial situation and problem statement, three main research goals can be deduced, see Figure 1-2. They all lead to the superior aim to improve the acceptance and application of engineering design methods in today's product development against the background of an increasing digitalisation and its consequences.

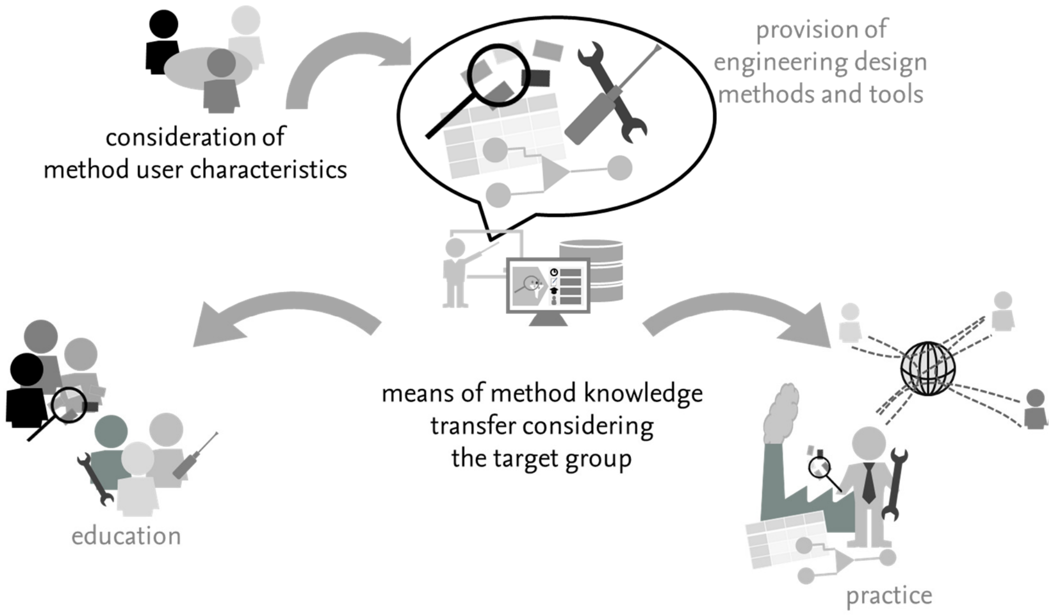


Figure 1-2 General goals of the research project

Based on the assumption that a higher acceptance of engineering design methods leads to a more frequent application of them, the first assumption addresses method provision approaches as a possibility to enhance this acceptance. If the method provision fits the circumstances and preferences of the potential method user and the team, the barrier to apply a method will decrease.

This is directly connected to the second assumption. It emphasizes the importance of the method user and the team when selecting a method for application. It is assumed that the increasing digitalisation of the working environment leads to varying team constellations, which demands more detailed considerations of the method user and the team when choosing methods and tools. As a consequence, this implies a method provision consisting of method descriptions and access possibilities considering method user characteristics. These characteristics can be objectively describing attributes like the composition of the team with multidisciplinary experts, the team size or the local distribution of the team. In addition, more soft aspects like competencies should be considered in a team-oriented method provision approach.

With the establishment of the third assumption, the considerations are widened to the training and transfer of method knowledge. This assumption states that the target group, for example students or engineering practitioners, influence on how knowledge is to be transferred. Thus, the third research goal aims at the development of different training concepts for design methods that consider the method user and the team on the level of target groups. The team-oriented method provision approach should be part of these training concepts for different target groups (students and engineering practitioners).

1.2.2 Research questions

To investigate the assumptions, six research questions were formulated. The research questions are closely connected to the assumptions in the way that one research question addresses the current state of the areas around the assumption whereas a second question focuses on a possible solution. Figure 1-3 shows the relations of the assumption A1 to A3 to the questions Q1 to Q6.

Research question Q1 *"How are engineering design methods provided in existing method descriptions and collections?"* deals with existing method provision approaches. Then, research question Q2 *"What are requirements on a suitable method provision in engineering design?"* demands requirements for a possible solution for assumption A1. Accordingly, research question Q3 *"How do method user characteristics influence the methods' application in engineering design?"* considers the current state on the influence of method user characteristics on method application detailing assumption A2. The answer to research question Q4 *"How can method user characteristics be identified and considered in method provision and application?"* tries to generate a concept for a team-oriented method provision. Research question Q5 *"What are success factors and barriers for method knowledge* *transfer in design education and practice?"* investigates the current state on method knowledge transfer to prepare the grounds for answering the last research question. Question Q6 *"What are successful means for method knowledge transfer considering the target group?"* aims at the development of training concepts for different target groups. The last two questions address assumption A3.

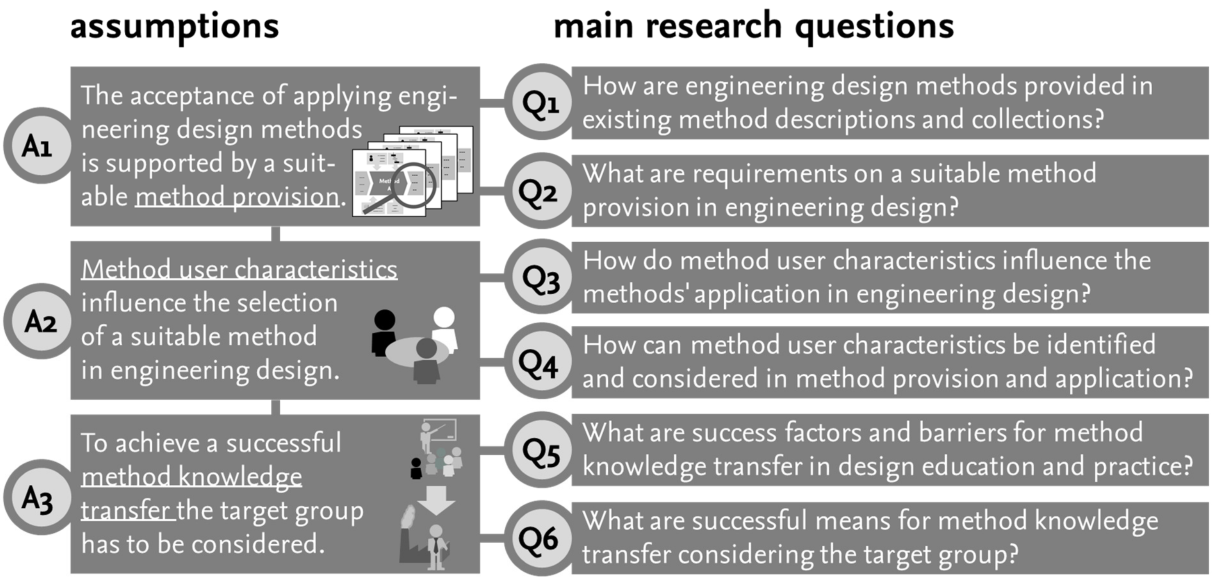


Figure 1-3 Relationship of assumptions and main research questions

The approach on how to investigate the research questions in the course of this thesis will be presented in the following section. Additionally, at the beginning of each of the chapters, the corresponding questions will be taken up and answered subsequently. A conclusion and reflection at the end of each chapter will emphasize the result by referring to the question.

1.2.3 Research methodology

The approach of this thesis is based on the Design Research Methodology (DRM) by Blessing and Chakrabarti (2009), see Figure 1-4. The DRM consists fundamentally of four stages. The first stage is the research clarification, in which the research goal is the main outcome. The next stage is the descriptive study I. Its purpose is to gain a better understanding of all influences on the research topic. This step can be assisted by literature reviews as well as survey and interviews. The third stage, the prescriptive study, aims at developing a solution or a support on the topic considered. The previous insights from the prior stages help to find a solution. This solution will then be evaluated in the descriptive study II (Blessing & Chakrabarti, 2009).

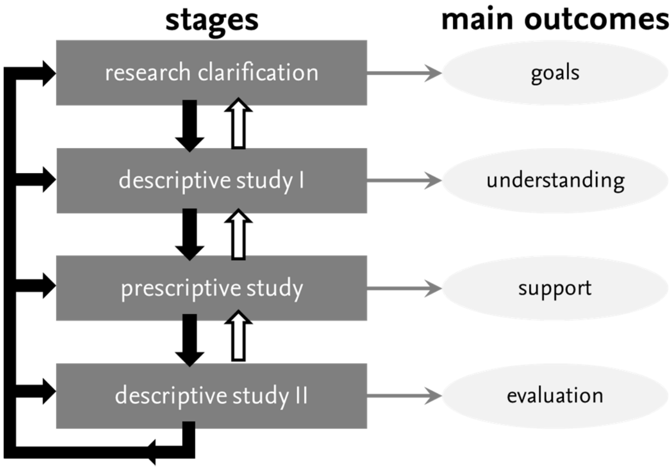


Figure 1-4 Procedure within the Design Research Methodology according to Blessing & Chakrabarti (2009)

In this thesis, all stages will be addressed. The focus is on the descriptive study I and the development of a solution within the prescriptive study: a concept for a team-oriented method provision and corresponding training. The state of the art reflects a wide field of research topics ranging from engineering design, training and transfer to team considerations originating in psychology. This is necessary to gain a better understanding of the presented research goal. The goal will be specified subsequently in chapter 3 in terms of the identification of the research gap and intended results. In the further course of the thesis, the research questions will be answered one by one. Figure 1-5 demonstrates the links of the research questions to the DRM stages in the columns on the right-hand side. Additionally, the main scientific research methods to approach the questions are indicated in this part of the figure.

Research question Q1, Q3 and Q5 serve the purpose of identifying the current state in the addressed research area. On this basis, the intended results of the thesis can be specified. These questions will mainly be answered by literature reviews and survey results. The survey used is the so-called MuPro-KMU study conducted by the Institute for Engineering Design, TU Braunschweig, within the European Union funded[2] homonymous research pro-

[2] The project called “Methodische Unterstützung der Produktentwicklung in KMU” (Methodical support for engineering design in SME) was funded by the European Regional Development Fund (ERDF).

ject from March 2014 to August 2014. The survey was provided online to employees of mainly small- and medium-sized enterprises from Lower Saxony, Germany. The 90 respondents belong to one regional large enterprise and five regional SMEs in different domains ranging from automotive applications to plant engineering. For further information see Bavendiek et al. (2014) or Vietor (2015). Additionally, expert ratings are used for the analysis of existing method provision approaches and for the analysis of the influential method user characteristics.

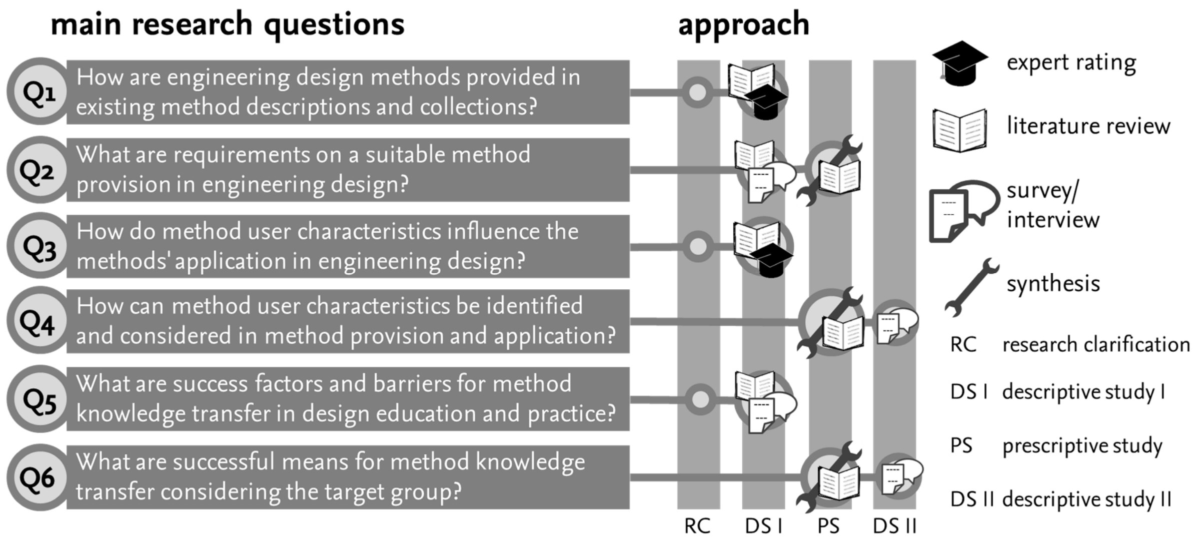


Figure 1-5 Assignment of research questions to phases of the DRM and applied scientific research methods and tools

The research questions focussing on the development of a support or a general synthesis are Q2, Q4 and Q6 as introduced before. For the development, the corresponding analysis results and literature are consulted. The answer of Q2, which is a requirements list on a method provision tool, is the basis for the development of the support addressed in Q4, which is a concept for a method provision tool. Q6 focuses on the method knowledge transfer and utilises the results from Q4 and Q5. Selected results like the concept for the method provision tool (Q4) and the training concepts (Q6) will be evaluated in the descriptive study II. The evaluations are not representative in general but serve as feedback from potential target groups on the generated concepts.

1.3 Thesis structure

This thesis consists of nine chapters. The structure is presented in Figure 1-6. The first chapter introduced the main assumptions and research goals. These were detailed by research questions and the scientific approach. In Figure 1-6 the research questions are assigned to the chapters where they are answered. Chapter 2 covers the basics for a deeper understanding of this research work. The major topics deal with the design methodology, especially design methods, the design organisation, mainly the development team, and knowledge transfer and training. The subsequent chapter 3 builds on the basics and clarifies the focus of this work by defining the intended results of this thesis.

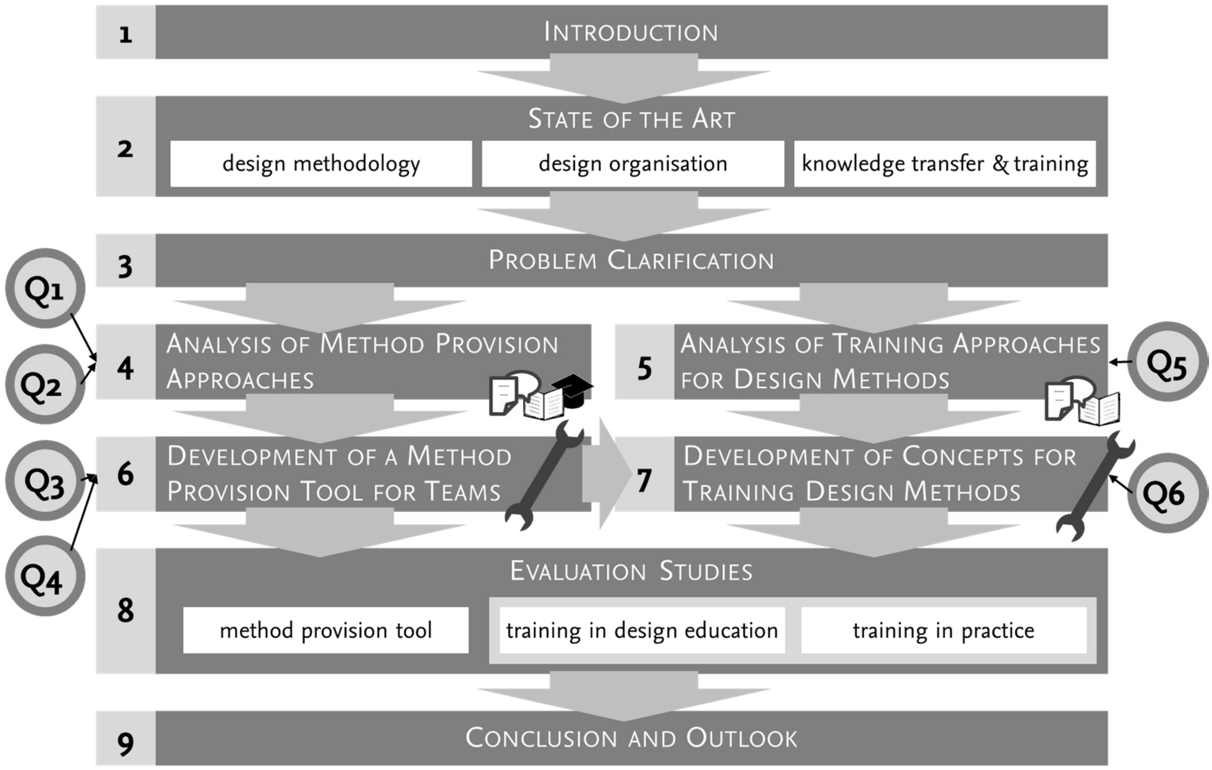


Figure 1-6 Thesis structure and relationship of research questions to the chapters

From this point on, the work is following two separate branches. On the left-hand side in Figure 1-6, chapters 4 and 6 focus on method provision approaches. This means, that the approaches focus on how to provide engineering design methods by describing and making them accessible to potential users. Chapter 4 analyses existing method provision approaches, whereas in chapter 6 a concept for a team-oriented method provision tool is developed. On the right-hand side in Figure 1-6, the focus is on knowledge transfer and training of engineering design methods. First, chapter 5 analyses training approaches for methods, which are then used in chapter 7 to develop training concepts while considering different target groups like students and practitioners.

With the aid of several evaluation studies in design education and practice the single elements that originated in chapter 6 and 7 are tested in chapter 8 and first feedback is gathered. The thesis closes with a conclusion and an outlook on potential further research work and applications in chapter 9.

2 State of the Art

"You have to be creative. It's the basics.
You can't be Picasso unless you know how to draw a real face;
then you can turn it upside down."
Diane English, American writer

For every research project it is essential to create some basics and to get to know the state of the art. So, this chapter will introduce relevant areas of research that concern the underlying research work as illustrated in Figure 2-1. The figure shows an areas of research and contribution (ARC) diagram with the topic in the centre and essential and useful research areas around (Blessing & Chakrabarti, 2009).

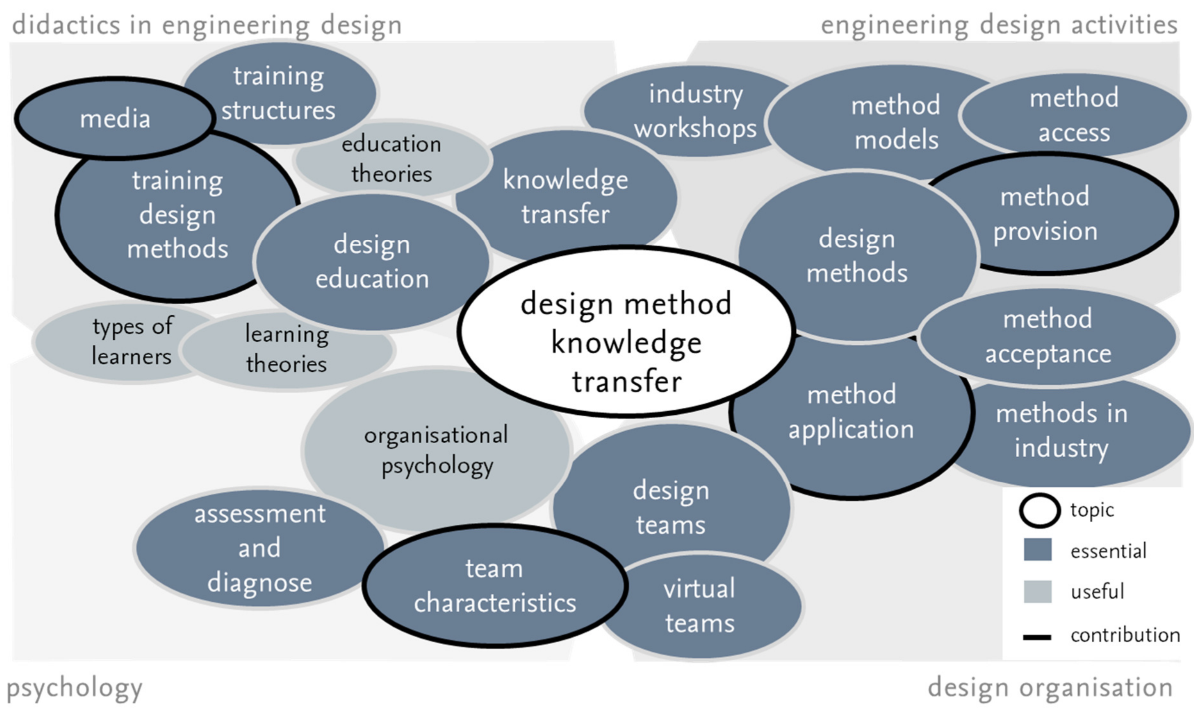


Figure 2-1 Areas of relevance and contribution of the underlying thesis

There are four superior fields of research addressed. The research is settled in the field of systematic design within engineering design. Therefore, two of the fields addressed are situated in this domain, which are engineering design activities and the design organisation, thus where the activities take place. Two further disciplines are needed to deduce relevant insights for the research work: psychology and didactics. The chapter is structured into three main parts. The first part on design methodology deals with systematic engineering design. The focus is on engineering design methods and their provision. The second part considers the design organisation using insights from psychology like assessing team characteristics. The third part refers to didactic basics that are used for method knowledge transfer and training. At the end of the chapter, the takeaway messages are summarized.

2.1 Design methodology

The focus within this section is on the engineering design process. The context of the underlying research work is described within the first part of this section presenting influences on and procedures in the design process. The second part addresses engineering design methods as support for systematic design, names influences on method application, potentials and problems. The third part shows existing approaches to provide methods to practitioners and students.

2.1.1 Development process in engineering design

This section allocates the underlying thesis in the field of engineering design within the product life cycle. Figure 2-2 illustrates the life cycle of a product from the initiating points like the technological field, business goals or market needs to the recycling and following use of the product. This thesis focuses on design methods that are mainly assigned to the development and design phase of the presented life cycle. This phase plays an important role in the whole process as decisions are made that influence the subsequent phases strongly, like the decision on material, geometry or functions.

The product development or design process can be seen as a problem-solving process, in which many participants are involved. Due to the complexity of today's products, the development is oftentimes realised in networks of collaborations, consisting of experts from different domains, e.g. mechanics, electronics, software, (Vietor et al., 2015). Thus, there arise a multitude of influences on engineering design processes that are presented in the following section. Afterwards, an overview of typical procedures and procedural models in engineering design will be given.

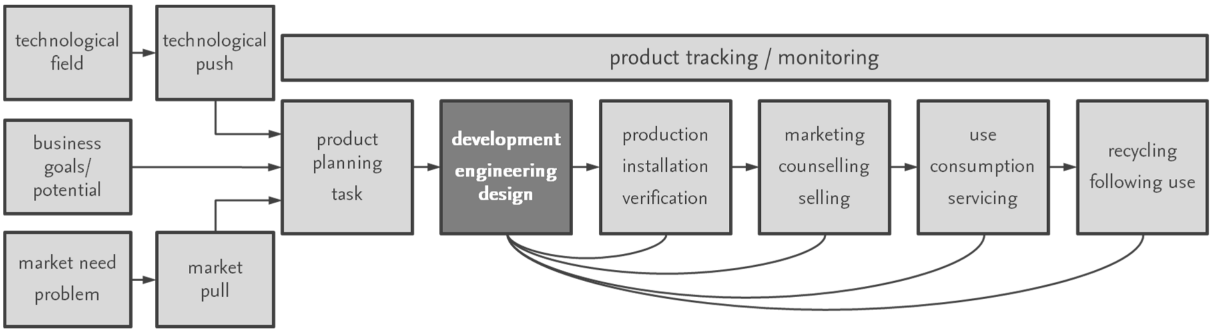


Figure 2-2 The development and engineering design in the product life cycle and its connections to other phases of the life cycle according to Vietor & Lachmayer (2016)

2.1.1.1 Influences on engineering design processes

Dylla (1991) differs between individual and external influences on design processes. Among the individual influences, he names skills and abilities of the designer or the design team like emotions, value system, skills, motivation, thinking and behavioural styles, action-related and factual knowledge. These aspects will be considered in detail in Section 2.2. External influences comprise the design task, available information, time and tools, the working environment, social and organisational context as well as external decisions.

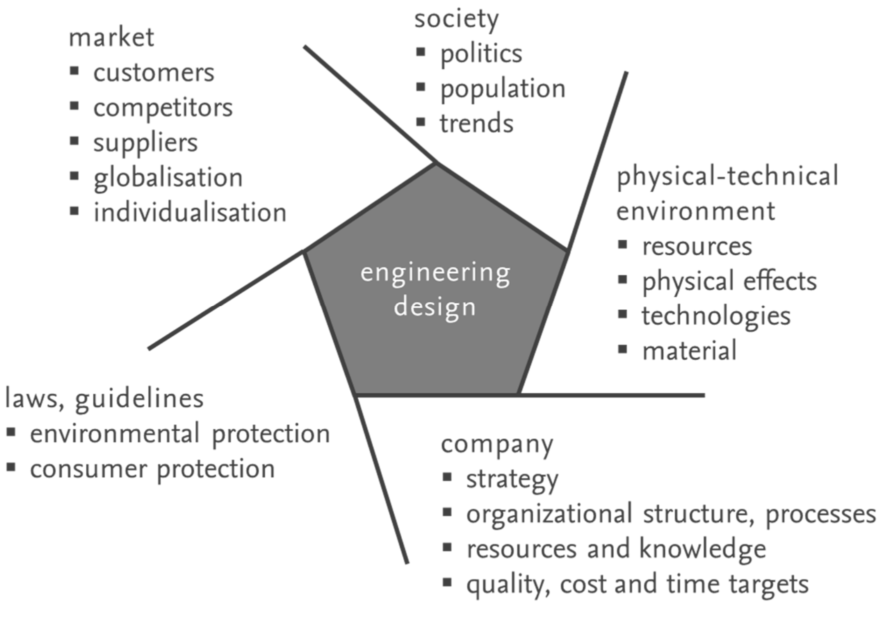


Figure 2-3 Influences on engineering design processes according to Vietor & Lachmayer (2016)

A broader view of the process is presented by Wallace and Hales (1987) who identified five level of resolution in their analysis of different design projects: macroeconomic (external influences), microeconomic (market, customer), corporate (management, strategy, etc.), project (task, team, techniques and output) and personal (knowledge, skills, attitudes, motivation and output). An approach on a similar level to describe design situations is proposed by Ponn and Lindemann (2008) or by Vietor and Lachmayer (2016). The latter summarise influencing factors among the categories of market, society, physical-technical environment, laws & guidelines and company. Company comprises the earlier mentioned individual or internal influences like resources and knowledge. These influences with some detailing aspects are illustrated in Figure 2-3.

Ponn (2007) analyses different research work on the design situation and its influences. He distinguishes the design task, the designer and the design team as well as further boundary conditions. He based his work on previous research, e.g. by Dylla (1991), Frankenberger (1997) or Grösser (1992). Frankenberger defines a detailed model of influences for describing critical situations in design processes. He uses the following categories and items:

- conditions of the individual (experience, competence, need for control, theoretical formation, subjective time pressure, motivation, quality standards, open mindedness, assertiveness, social knowledge, action-orientation),
- conditions of the team (team organisation, power, quality of leadership, team atmosphere, informal hierarchy),
- boundary conditions (distribution of tasks, coordination of tasks, local distance, restrictions, objective time pressure),
- task (novelty of task, frequency of change),
- design process (quality of goal analysis, quality of solution analysis, communication, availability of information, quality of solution generation, solution progress, opportunistic action, acceptance of requirements and solution, duration, frequency of discussions),
- output (functional compliance, costs, dates).

Comparing the influences of the different authors, it becomes clear that the design team and the designer have a great impact on the design process and its success. Thus, Section 2.2 goes into more details on this topic. The next sections address procedures in engineering design and support possibilities, independently from the designer and the team.

2.1.1.2 Procedural models and models for problem-solving in engineering design

A procedure can be descriptive or prescriptive (Araujo, JR, 2001). It can define a complete development process, e.g. in an enterprise, or it can be related to more basic processes like simple problem-solving processes. Hubka et al. (1980) define the term procedural model as follows: “A procedural model represents a concept for the execution of the design process, usually for ideal conditions of the factors of the design process and for all types of design problem.” (Hubka et al., 1980) Thus, a procedural model is an abstract de- or prescription of a procedure. Vietor and Lachmayer (2016) use the term “sequence” to define procedural models: “A procedural model is the illustration of a sequence of operations with the aim to plan, control and reflect single operations as well as to facilitate the orientation within the sequence.” (Vietor & Lachmayer, 2016)

As procedural models can be used on different abstraction levels, Lindemann (2009) introduces a classification of these models according to their resolution as shown in Figure 2-4.

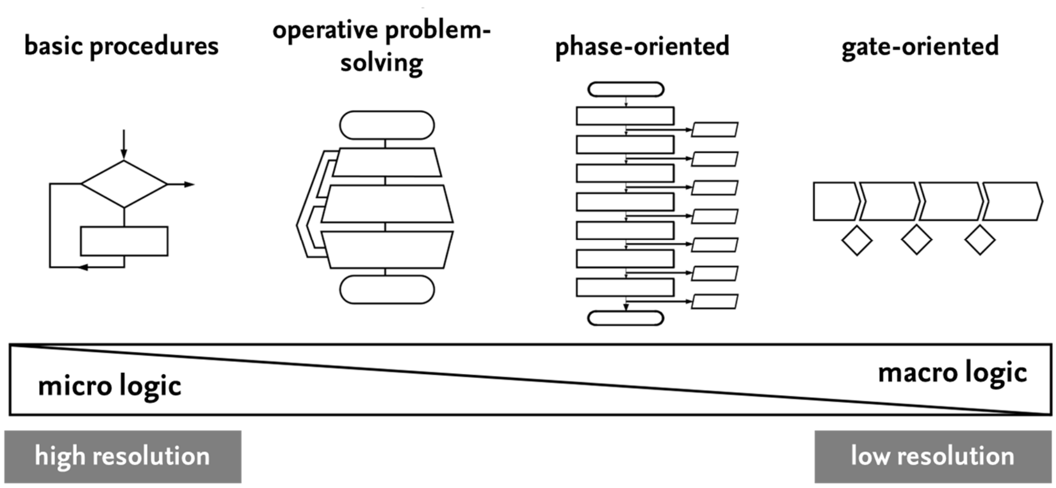


Figure 2-4 Classification of procedural models according to Lindemann (2009)

On the micro logic level, basic procedural models like the TOTE (Test Operate Test Exit)-Scheme, e.g. Ehrlenspiel (1995), are placed. On the next level, operative problem-solving procedural models can be found. Examples of these models are the Problem-Solving Cycle by Ehrlenspiel (1995) and the Micro Cycle of Problem-Solving according to VDI guideline 2206 (Verein Deutscher Ingenieure, 2004). As a method or procedure within the operative problem-solving, the SPALTEN method by Albers et al. (2005) can be mentioned. The activities of problem-solving give the name for this procedure in terms of their initial letter (in German) (Albers et al., 2005):

- Situation Analysis (Situationsanalyse)
- Problem Containment (Problemeingrenzung)
- Search for Alternative Solutions (Alternative Lösungssuche)
- Selection of Solutions (Lösungsauswahl)

- Analysis of the Level of Fulfillment (Tragweitenanalyse)
- Make Decision/Implement (Entscheiden/Umsetzen)
- Recapitulate/Learn (Nacharbeiten/Lernen)

The process from a problem to a solution in general is supported by this level of procedural models. Hereby, the distinction between procedural model and method is not always clear. A differentiation will be given below (see Figure 2-5).

The subsequent level, the phase-oriented models, is widely-spread in design methodology. Examples are the VDI guideline 2221 (Verein Deutscher Ingenieure, 1993), the Braunschweig Procedural Model (Franke et al., 2006), and the Munich Procedural Model (Lindemann, 2009). All these models have in common that they prescribe different phases or stages to be passed in more or less fixed orders. In general, iterations or jumps from one to another phase are scheduled. The VDI guideline 2221 (Verein Deutscher Ingenieure, 1993) and the Braunschweig Procedural Model (Franke et al., 2006), for instance, define four superior design phases being task clarification, conceptual design, embodiment design and detail design. Rather than any other level, the phase-oriented level includes also the integrated Product engineering Model (iPeM) by Albers, e.g. Albers et al. (2016). This model consists of the triple of target, operating, and object system (German: Ziel-, Handlungs- und Objektsystem, see e.g. Albers and Meboldt (2007)) as well as of the problem-solving method SPALTEN, and activities of product engineering or process phases (Bursac, 2016).

On the macro logic level, gate-oriented procedural models are located. These types of models are often used in automotive engineering design processes as exemplarily described by Braess and Seiffert (2013). Gate-oriented procedural models define gates or milestones that have to be passed before another step may start.

Procedural models are closely related to methods and tools that are applied in the design process (Araujo, JR, 2001). According to Lindemann (2009), a procedure or a procedural model describes what steps have to be done to achieve a goal, for instance, the successful design of a component, whereas a method prescribes how to do the steps (see Figure 2-5). Thus, a method can support different steps of a procedure, but it can also originate different procedures (Araujo, JR, 2001). To provide a better understanding of the term “method”, the next section deals in detail with design methods.

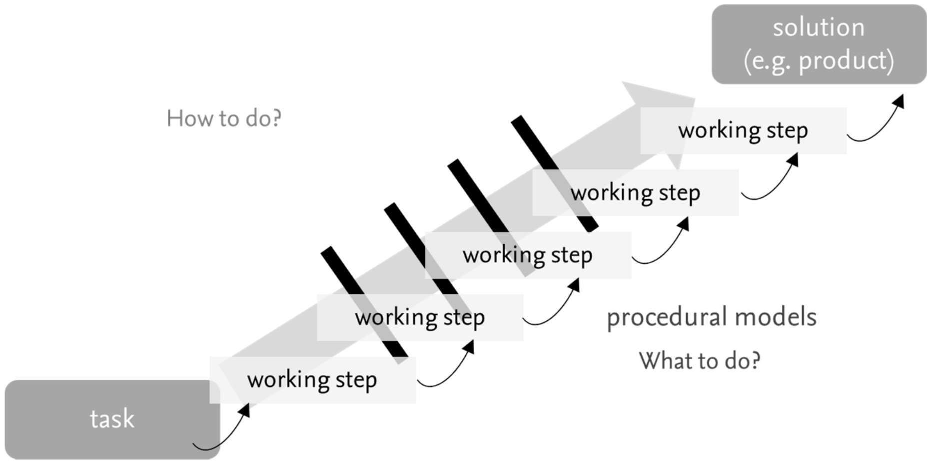


Figure 2-5 Integration of methods and tools in the engineering design process and differentiation to procedural models according to Vietor & Lachmayer (2016)

2.1.2 Engineering design methods

After defining the term “method”, different classifications of engineering design methods and influences on method application will be presented. Subsequently, potentials and barriers of method application as well as resulting requirements on providing methods will be explained.

2.1.2.1 Definition

The term “method” is widely-spread and there are various different understandings and definitions. Araujo, JR (2001) gives an overview of 19 different definitions from literature and dictionaries that clearly demonstrate the ambiguity of this term. Most definitions have in common the prescriptive character, the description of a procedure and the goal-orientation. This fits the origin of the word, being the Greek word “méthodos” meaning way or path along (Araujo, JR, 2001). A commonly used definition is given by Lindemann (2009) who defines “method” as a “description of a rule-based and planned action to perform certain activities according to its specification” according to a translation of Reiss et al. (2017). A similar definition is given by Vietor and Lachmayer (2016): “A method provides an operatively applicable thinking and behaviour pattern to achieve a goal.” Oftentimes, the term “method” is used interchangeably with other terms like “tool”, “technique”, “procedure” or “model” (Araujo, JR, 2001). Some authors differentiate between “method” and "tool", though. According to Vietor and Lachmayer (2016), for instance, a "tool supports a method application by its inherent logic." In this thesis, this differentiation between method and tool is roughly utilised but cannot be made consequently. To give an example, the documentation of requirements is seen as a method, whereas the requirement list is the tool for the documentation. Commonly, the Requirement List is referred to as method for task clarification, e.g. Ehrlenspiel (1995), Feldhusen and Grote (2013). A strict differentiation is, thus, not pursued when the Requirement List is called a method in this research work. In the further course, the term "additional tools" will be used to clearly denote tools in contrast to a method.

2.1.2.2 Classification of methods and influences on method application

Due to the variety of engineering design methods, classifying the methods helps to give an overview and to select them for usage. Many approaches to method classification are known (Braun & Lindemann, 2003). Thus, Braun and Lindemann (2003), see also Braun (2005), distinguish between three different approaches to classify methods for selection: assignment to superior process (German: methodenordnend), assignment to method attributes (German: methodencharakterisierend) and assignment to elementary tasks (German: elementarmethodisch), see Figure 2-6.

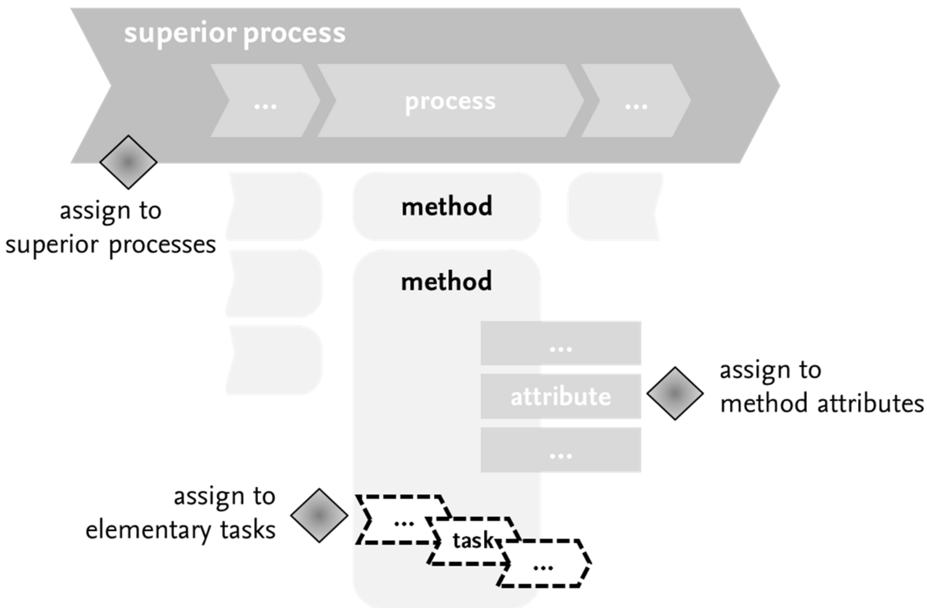


Figure 2-6 Different approaches to classify methods as starting points for method selection according to Braun & Lindemann (2003)

Classifications according to the assignment to a superior process can be the life cycle of the product (Ehrlenspiel, 1995), stages or phases in the complete design process (Ehrlenspiel, 1995) or working steps in the conceptual design phase (Feldhusen & Grote, 2013). Furthermore, some authors suggest engineering disciplines or a hierarchy of methods for classification purpose (Gausemeier et al., 2000). Classifications according to the assignment to method attributes were, for instance, presented by Birkhofer et al. (2001) using the Process-oriented Method Model (see Section 2.1.3.1) for characterising purpose, by Helbig (1994) using properties of design methods or by Reinicke (2004) using properties of user integration. Classifications according to the assignment to elementary tasks are exemplarily proposed by Zanker (1999), Zier et al. (2012) or Zier (2013).

Ponn (2007) gives an overview of classifications of methods used within method collections. He differs between the main categories:

- general methods,
- methods for organisation,
- methods for analysis, planning, task clarification and structuring,
- methods for solution generation,
- methods for decision-making and evaluation,
- methods for information processing,
- further methods like Design for X or optimisation.

There are various aspects that influence the method application and, thus, the selection and also the classification of a method. Braun (2005) provides a complex overview of intrinsic and extrinsic criteria for a method application. Among the intrinsic, he names, for instance, the aim of the method, the adaption, the input, the situation or training possibilities. As extrinsic criteria, six groups are differentiated. These are human-related resources, issue-related resources, information resources, task, company and externalities like market or concurrence. As a method is applied in the context of an engineering design process, Ponn (2007) uses the same influencing factors for method application as for the whole design process divided in design task, designer and design team as well as further boundary conditions.

2.1.2.3 Potentials and barriers of method application

Systematic approaches and the usage of design methods provide great potentials like some studies reveal. Daalhuizen (2014), for instance, shows a positive correlation between method usage and performance within a small sample size. Another author (Graner, 2013) analysed more than 400 development projects in practice and could prove the supporting effect of an integrated method application for engineering designers. Within the projects analysed, an intensive method application was correlated to a new product's success. Bavendiek et al. (2015) found a positive correlation of method usage in meetings to the meeting satisfaction as well as to the task performance. Findings from a survey in practice (Araujo, JR, 2001) additionally revealed an improvement in the quality of task execution by supporting methods and improved resultant products. Furthermore, Araujo, JR (2001) reports reduced time spent on problem-solving and reduced costs in the development as potentials of methods in practice. Finally, he states an improvement of control and communication within the development process and the team. The communication aspect is also stressed by Strasser (2004), who also mentions the aspects of fostering creativity and the advantage of the self-documentation characteristics of methods. All these potentials are opposed to some barriers in Table 2-1, which will be described subsequently.

Table 2-1 Selected potentials and barriers of method application in practice

potentials	barriers
▪ improved performance ▪ improved meeting satisfaction ▪ improved execution of task supported by method ▪ improved quality of the resultant product ▪ reduced time effort ▪ reduced costs ▪ improved control ▪ improved communication in team ▪ fostered creativity ▪ self-documentation of working steps	▪ diverting attention from task to method ▪ too much time effort on method application ▪ too little or worse results compared to traditional way ▪ over formalisation and increased bureaucracy ▪ mismatching of method and problem/task to solve ▪ degree of training and user abilities ▪ wrong implementation/realisation of method ▪ evaluation of method's benefits unclear ▪ abstract and unclear terminology and representation ▪ "not invented here"

Barriers hinder the excessive application of methods in practice. In contrast to the potentials reported, too much time spent on method application with little results compared to no method application is named as drawnbacks of methods (Araujo, JR, 2001; Jänsch, 2007). Especially tools, but also methods tend to divert the attention from the problem to the tool or method, which results again in more time consumption. Oftentimes, the implementation of more complex methods implicates an increased bureaucracy due to more information generated and an over-formalisation (Araujo, JR, 2001). Another problem is the mismatch of methods and tasks or problems to be solved or the wrong implementation and realisation (Araujo, JR, 2001). Schmidt-Kretschmer and Blessing (2006) list as further barriers the abstract and unclear terminology and representation as well as the unclear evaluation possibilities to prove the method's benefits. Similar problems were reported by Jänsch (2007). Some authors also mention the missing training of methods as well as the missing consideration of designers' needs as barriers, e.g. Birkhofer et al. (2005), Geis, Bierhals et al. (2008), Schneider et al. (2006). Finally, one small but relevant aspect is the syndrome of "not invented here". Harrison and Tatar (2011) express it in these words: "Design methods are like toothbrushes. Everyone uses them, but no one likes to use someone else's." (Harrison & Tatar, 2011) Thus, there are also some acceptance problems regarding methods and their application.

2.1.2.4 Requirements on providing methods

To overcome those barriers and to address the potentials mentioned, several authors dealt with requirements on methods, providing methods or advice on how to transfer them to practice (see also Section 2.3). This section contains a short overview of requirements found in literature; a detailed analysis coming up with a large requirement list for method provision will be presented in chapter 4, for method training in chapter 5.

At first, measures to meet the expectations of practice are requirements for methods themselves. They shall require a little effort for training and learning, shall be easy to use with a low time effort and shall produce convincing results for complex problems. Thereby, they shall be integrated in existing processes (Schmidt-Kretschmer & Blessing, 2006). Lohmeyer et al. (2014) distinguish between individual and organisational aspects for accepting methods and tools. They name transparency, connectivity, communication & agreement, standardisation and flexibility & scalability as important aspects. According to Hubka (1983) and Araujo, JR (2001) it is essential to give clear instructions and information on a method for implementing it successfully. According to Helbig (1994), aim and procedure of a method are most relevant to understand a method. Wach (1994) demands a graphical presentation of methods due to the human visual preferences. Schmidt-Kretschmer and Budych (2009) analyse existing method descriptions in Feldhusen and Grote (2013), Ehrlenspiel (1995), Cross (2007), Lindemann (2009) and Otto and Wood (2001) regarding the seven dialogue principles of ISO 9241-110:2006 (Ergonomics of human-system interaction - Part 110: Dialogue principles). They come up with requirements for method provision as listed in Table 2-2. Requirements that are italicised are not yet considered in the method descriptions analysed by Schmidt-Kretschmer and Budych.

Table 2-2 Requirements on method provision according to Schmidt-Kretschmer and Budych (2009)

suitability for the task ▪ flexible description of method application ▪ explanation of terms	suitability for individualization ▪ modular structure ▪ consideration of different user knowledge
self-descriptiveness ▪ explicit mentioning of method aim ▪ assignment of method to process ▪ method collections ▪ overview of working steps/procedure ▪ *specification of learning target* ▪ advanced organiser	suitability for learning ▪ *exercises* ▪ *unsolved problems as stimulation* ▪ *reports from practice* ▪ direct appeal to reader ▪ *depict clearly* ▪ repetition of important information
conformity with user expectations ▪ *analogies and comparisons* ▪ examples from practical work ▪ *excursus*	controllability ▪ prefixed overview ▪ clear paragraphs/groups of information ▪ summary
error tolerance ▪ *assistance for exercises*	

Only the *assignment to the design process* and a *prefixed overview* were rated positively. The lasting requirements were neither positively nor negatively rated over all method provisions.

The method descriptions considered in this analysis are mainly text-based descriptions within a book. The next section focuses on further, more structured method provision possibilities.

2.1.3 Provision of design methods

Ponn (2007) differentiates method definition, method description, method collections, method selection and method adaptions regarding research work done in the field of providing engineering design methods. Research on method definition deals with possibilities to define the term "method", research on method descriptions focuses on the way to describe and or present methods to others, whereas method collections contain multiple methods that are described in a unified manner. Research on method selection has the aim to help identifiying suitable methods for an application situation and research on method adaptions, finally, deals with ways to fit a method to its application situation.

This classification will be used to structure existing literature and to give a brief overview of relevant research work in these fields. The topic of method definition was already presented in Section 2.1.2.1. So, the next section will start with method descriptions.

2.1.3.1 Method description

According to Ponn (2007), diverse authors deal with the topic of describing methods. He names, amongst others, Birkhofer et al. (2001), Birkhofer, Kloberdanz, Berger et al. (2002), Braun (2005), Dobberkau (2002), Grösser (1992), Helbig (1994), Lindemann (2009) and Zanker (1999). Most of this research work was conducted to identify relevant attributes or aspects to describe methods in a way that the method is comprehensible to others.

An overview of different method properties or attributes collections is given by Ponn (2007). These collections contain beside the properties and attribute corresponding values if described by the authors. Grösser (1992), for instance, differs between output (like type of output or degree of output formalisation), input (like application costs, team size or time effort), characteristics (like domain and origin), function (like strategy, type of problem-dealing) and structure (like type of problem-solving, degree of formalisation). Another description approach is presented by Helbig (1994), who uses an even more detailed collection of properties and attributes. Main categories are aim, application conditions, application, consequences and administration. Among the application conditions, the group qualification considers the team or user of a method with aspects like factual knowledge, method knowledge, skills, attitudes and experiences (Helbig, 1994). This collection of Helbig includes more than 60 different aspects, which makes descriptions of methods with all these criteria excessive. Oftentimes, the target group of method descriptions are other researchers, which justifies complex and large descriptions, especially when introducing new methods. But rarely literature made for practitioners is clearly differentiable from this more basic literature intended for researchers (Araujo, JR, 2001). Thus, some approaches were taken to develop clear method descriptions that enable the application of a method with their aid.

A common model to describe methods in engineering design context is the Process-oriented Method Model which was presented by Birkhofer, Kloberdanz, Berger et al. (2002). It consists of process and access modules as illustrated in Figure 2-7. Process modules are in- and output, sequence, user, general conditions, hints and working aids. The classification, relation to other methods, specification and links belong to the access modules. For detailed descriptions see Birkhofer, Kloberdanz, Berger et al. (2002).

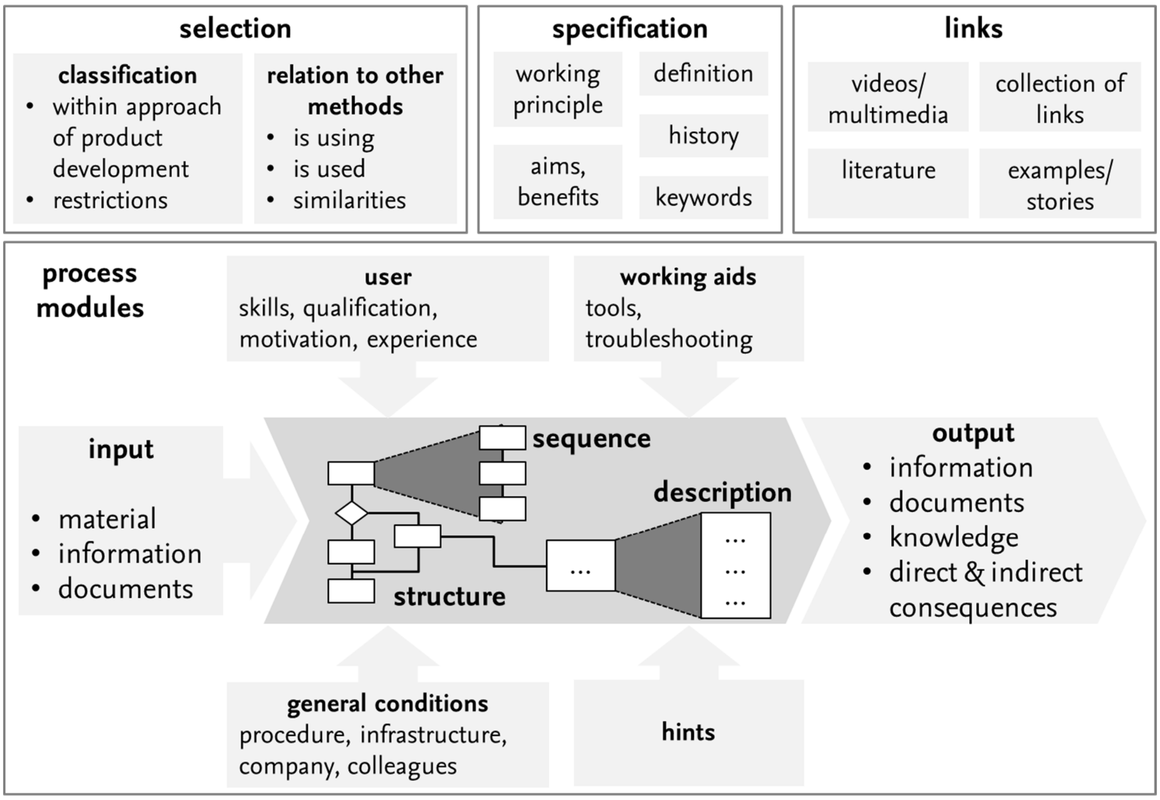


Figure 2-7 Process-oriented Method Model according to Birkhofer, Kloberdanz, Berger et al. (2002)

2.1.3.2 Method collections

The next step from a method description is the step towards a method collection. A collection contains multiple methods that are described in more or less standardised manners (Ponn, 2007). The traditional way to provide method collections are paper-based or printed collections, e.g. as main content or appendix of a book. Examples are basic literature on engineering design methods like Feldhusen and Grote (2013) respectively Pahl et al. (2003), Lindemann (2009), Cross (2007) or Otto and Wood (2001). An overview of methods and a classification concerning the method aim is given in the VDI guideline 2221 (Verein Deutscher Ingenieure, 1993). Detailed descriptions of methods are exemplarily contained in the collections of Strasser (2004), Dobberkau (2002), Eversheim (2003) or Ponn (2007) respectively Lindemann (2009). An impression of some of the method descriptions within such a collection is illustrated in Figure 2-8.

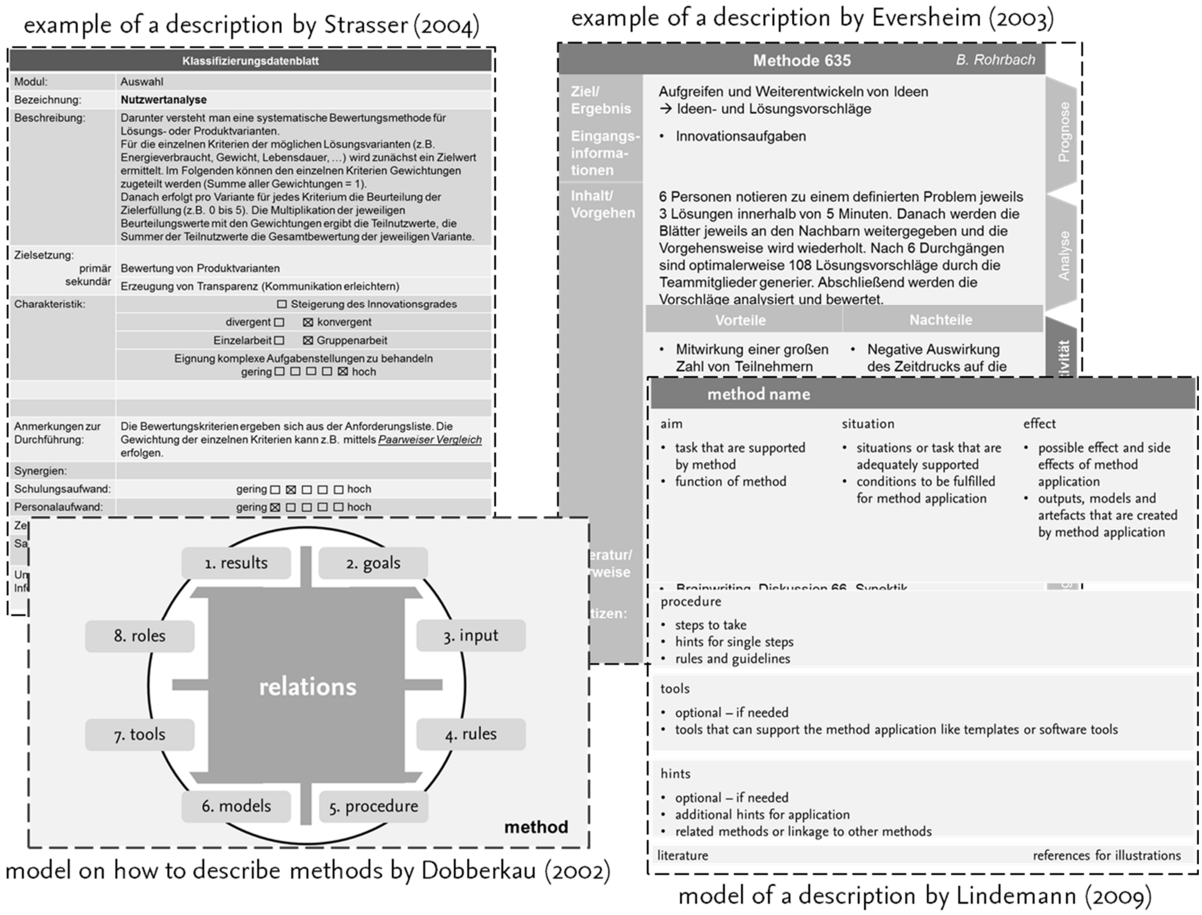


Figure 2-8 Examples of method descriptions within method collections

Besides the paper-based method collections, the usage of web-based or digital method collections started at the beginning of the 21^{st} century. One of the first web-based method collections is the "MAP-Tool" (RPK - Thomas Paral, Karlsruhe, 2000) containing 144 methods from product planning to product launch onto the market. Another collection, introduced by Franke et al. (2003), is the "GINA – Methodos" portal that includes more than 60 method descriptions and additional design catalogues (eKAT) or TRIZ tools (Franke et al., 2011). Further platforms that provide different method descriptions as a collection are the pinngate, e.g. Jänsch et al. (2006), Weiß and Birkhofer (2006), CiDaD (Lehrstuhl für Produktentwicklung, TU München, 2008) or MEPORT (GfU Gesellschaft für Unternehmenslogistik mbH, 2009) portals. More recent approaches are the WiPro portal (TIM, 2013) or the mobile application InnoFox, e.g. Albers et al. (2014), Albers et al. (2015). The amount of information on each method varies from portal to portal and also from method to method. The focus of methods depends on the origin of the collection. The here mentioned platforms originate mainly from engineering design or product planning. A detailed overview of 25 method collections will be presented within the analysis of chapter 4.

Further types of method collections can be method cards like those distributed by IDEO (2003) or other templates and support tools provided online or in digital format like those for TRIZ (TRIZ Consulting Group).

2.1.3.3 Method selection and access

According to Araujo, JR (2001), the structured selection of method started with Jones (1992) who published his book on design methods first in 1970. He proposed a matrix with input and output parameter for the selection of suitable methods. The methods and tools are located in the cells of the matrix. A similar approach is introduced by Hubka (1983) who suggested a design catalogue for a structured access to engineering design methods. He claims the range of use, the type of effects and the requirements for the states of the factors as most relevant to practitioners for selecting a method (Araujo, JR, 2001).

Daalhuizen (2014) describes the process of method usage with five steps: (1) perception of need, (2) search for method, (3) selection of method, (4) learning to use method, and (5) applying method. Via method collections with access options, the second and third step (search and selection) can be supported by one tool. Some of the previously presented portals but also some of the paper-based method collections provide access in different ways. Figure 2-9 displays some examples of web-based solutions to search and select methods. The MAP-Tool, for instance, uses a matrix to access methods regarding the product life cycle or phase in the design process. The InnoFox application allows accessing methods via the earlier presented iPeM model (Albers et al., 2016). Further platforms use simple filter options (TIM, 2013), pictures and questions like the Design Kit (IDEO) or sliders and buttons with selection options (mediaLABamsterdam B).

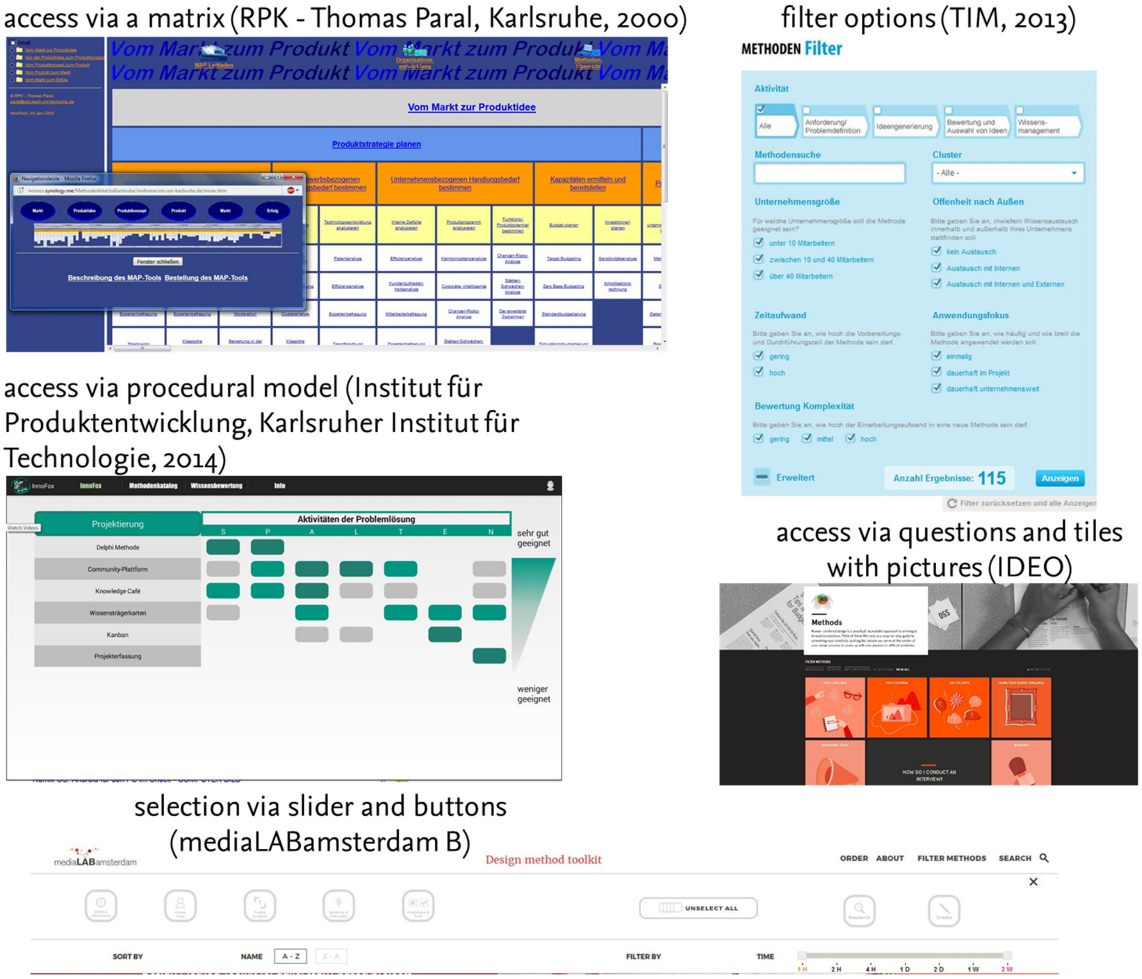


Figure 2-9 Different possibilities to access or select methods in digital method collections

Within the Munich Method Model (Braun & Lindemann, 2003), the selection, adaption and application of methods are described and supported. For the method selection, Braun (2005) provides a checklist that contains 29 questions on different aspects of the underlying task, the boundary conditions and further aspects on resources. The steps to undertake are first answering the questions and second to compare the answers to the values of the methods. A matching helps to find a suitable method. Ponn (2007) presents different so-called context factors from the task or product, from the designer and the design team and from boundary conditions. Like Braun, he assigns values to those context factors that help matching adequate methods. Generally, Ponn (2007) differs between four starting points for method selection: situation, task, method and procedural models.

2.1.3.4 Method adaption

Method adaptions are required to fit the method to the needs and boundary conditions of the situation in which it shall be applied. The Munich Method Model (Braun & Lindemann, 2003) comprises steps and hints on how to adapt methods to the situation. Further research work dealing with method adaptions is presented, for instance, by Dobberkau (2002), Reinicke (2004) or Zanker (1999). In this research, the adaption of methods results directly from the analyses on method user characteristics and their influences on the method application. For detailed information on the topic of method adaptions, see e.g. Braun (2005).

2.2 Design organisation

The design organisation sets the framework for engineering design tasks. Over the past decades, the organisation of work, the distribution of tasks and the scope of engineering design has changed. Feldhusen and Grote (2013) describe the change from an OEM (original equipment manufacturer) and permanent suppliers scenario to more cascades in the engineering design to a broker collaborating with temporary partners in the future (see Figure 2-10). The organisation of work influences amongst other things the teamwork. Coming from local face-to-face teams, virtual or locally distributed and multidisciplinary teams collaborate more and more in current and future scenarios. Thus, this section will first highlight relevant aspects of teamwork in general and then focus on the particularities of virtual or locally distributed teams. In each case, definitions, potentials and challenges as well as characteristics of teamwork will be described.

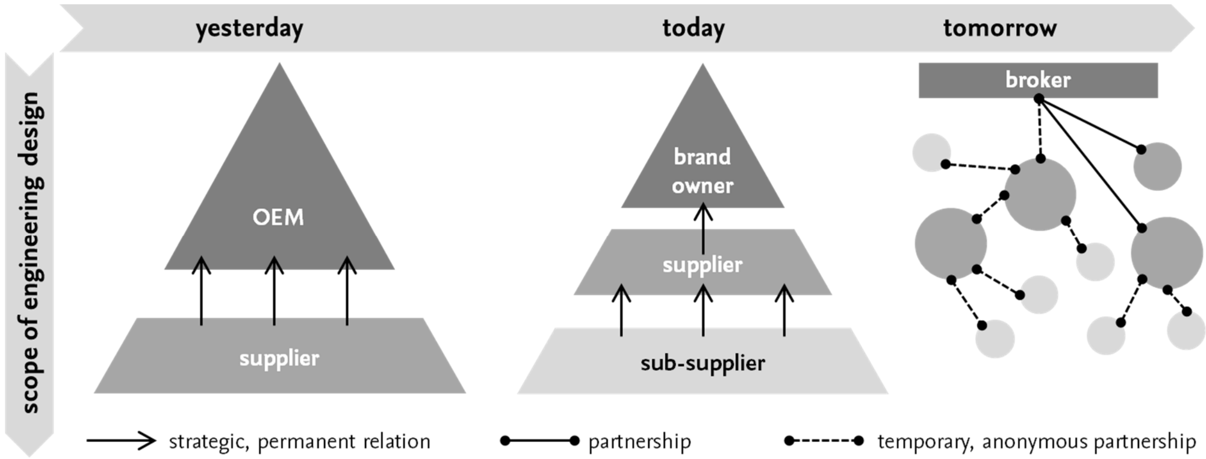


Figure 2-10 Change of the work's organisation in engineering design according to Feldhusen & Grote (2013)

2.2.1 Engineering design teams

Designers as individuals are seen as a major influencing factor on design and respectively on the product to develop, see Feldhusen and Grote (2013), Nieberding (2010), Tjalve (1979). Their abilities, skills and knowledge are important to the success of design processes. More and more research work focuses on the design team and its impact on design (Lutters et al., 2014; Nieberding, 2010). Besides team size, other aspects of research are expertise, experience, competencies, capacity and capability. Lutters et al. (2014) stress the team composition as "consequential impact on the project". The following section gives a definition of a team in general and highlights potentials and challenges in the engineering design context.

2.2.1.1 Basics on teamwork

According to literature, there are many different definitions of the term "team". For instance, an overview is given in Kauffeld (2001). Most of the definitions include the following four aspects when defining a team (Hoegl et al., 2001; Kauffeld, 2001; van Dick & West, 2013):

- identity,
- cohesion,
- common goals,
- three or more team members.

Identity means that the team members are perceived as a team by others and that they perceive themselves as a team as well (Hoegl et al., 2001). The team members depend on each other and have to interact with one another (Kauffeld, 2001). This mostly results in a kind of team spirit also called cohesion (van Dick & West, 2013). A team has a common goal that it wants to achieve (van Dick & West, 2013). In the context of engineering design, this goal might be the development task. The last aspect considers a team to be a social system of three or more members (Hoegl et al., 2001; Kauffeld, 2001). A complete definition can be according to Hoegl et al. (2001):

> *"A team is a social system consisting of three or more members, whose members perceive themselves as a team and are perceived as a team by others as well, and who collaborate to achieve a common goal."*

Teamwork has not always been seen positively. Although there were some attempts to introduce informal or formal teamwork in the industrial sector between the 1950s and 1980s in Northern America and Europe, teamwork was not evaluated as beneficial. A study of the Massachusetts Institute of Technology (MIT) in the 1990s revealed a higher output of innovations from Japanese companies compared to American and European ones. Concepts like Kaizen (Imai, 1986) and Total Quality Management (Ishikawa, 1991) were mentioned as catalysts for innovation. These concepts build on teamwork as one key aspect. Henceforward, teamwork has been considered more and more relevant in industrial context. A further reason for focussing on teamwork as a new element is the increasing complexity of products due to new technologies resulting also in new organisational structures. In addition, the growing concurrence due to a shift from a supply to a demand market is another reason (Kauffeld, 2001).

Subsequently, one potential of teamwork is the reduction of task complexity using synergies in teamwork. Ideas and knowledge can be added up and shared. Team members can learn from each other and control the results of others. A further advantage of teamwork is an increased motivation and satisfaction of each team member (Badke-Schaub, 1994; Geis, 2011; Nerdinger et al., 2014).

However, by increasing the number of participants of a task, the coordination and communication effort increases as well (Hoegl, 2005). Another challenge of teamwork is the tendency of "group thinking". This means that a team does not make a good decision because each individual tries to preserve team cohesion and, thus, contributes less forcefully (Janis, 1972). Although an increased motivation of each team member is a capacity of teamwork, teamwork can also turn disadvantageous when it comes to “social loafing”. Social loafing is called the effect when each member of a team performs less compared to performing alone (Latané et al., 1979). This effect can cause reduced motivation of all team members. Furthermore, using simplifications and economy trends is more common in teams compared to individual work (Badke-Schaub, 1994). The mentioned potentials and challenges are summarized in Table 2-3.

Table 2-3 Potentials and challenges of teamwork according to Badke-Schaub (1994), Geis (2011) and Nerdinger et al. (2014)

potentials	challenges
▪ reduction of complexity by synergies and adding up ideas ▪ controlling and questioning of planning and results ▪ learning effects by learning from each other ▪ increased acceptance, satisfaction and motivation of team members	▪ groupthink to preserve group cohesion ▪ reduction of motivation through “social loafing” ▪ coordination and communication problems ▪ cognitive and organisational simplification and economy trends

2.2.1.2 Team characteristics and competencies

So called input-process-output (IPO) models are used to better understand the team performance, influences on teams and their impact on success. These models structure influences on teamwork in input and process. Then, they assign potential outputs as indicators for successful teamwork (Hackman & Morris, 1975; Kauffeld, 2001). Regarding the input, relevant characteristics of a team are listed as demonstrated in Figure 2-11.

These inputs will be considered in the following in detail as they can grant valuable insights for the latter team-oriented method provision which is the aim of the thesis. Hence, the process can be seen as a method application. The output is of secondary interest because the influences on a team due to the method application are not primarily considered. One of the earlier IPO models by Hackman and Morris (1975) is exemplarily presented in Figure 2-11.

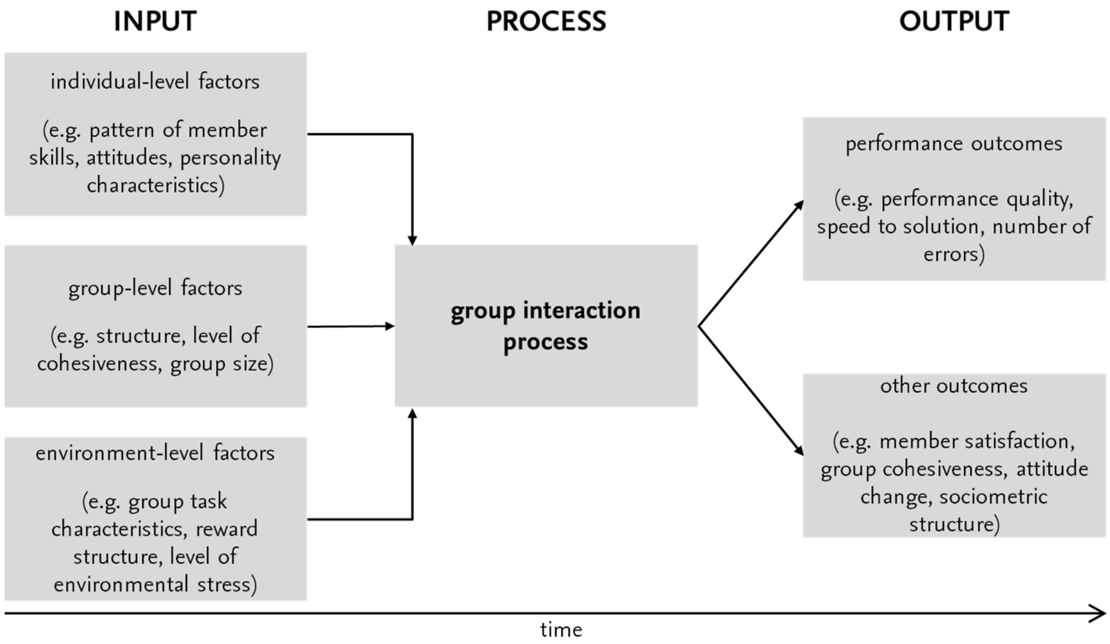


Figure 2-11 The input process output model (IPO) according to Hackman & Morris (1975)

The input is differentiated in individual-level, group-level and environmental-level factors. For this research work, the first two factor groups are most relevant. On the individual-level, the individual team members are considered with respect to their knowledge, skills, abilities and other characteristics (KSAOs or KSA) which can be combined to higher-level variables like team composition (Mathieu et al., 2013). An overview of possible KSAOs on the individual-level is given by Nerdinger et al. (2014) as illustrated in Figure 2-12. Age, gender, cultural background and education/formation are listed among demographical characteristics. Other categories are know-how and experience, personality, value system and social status.

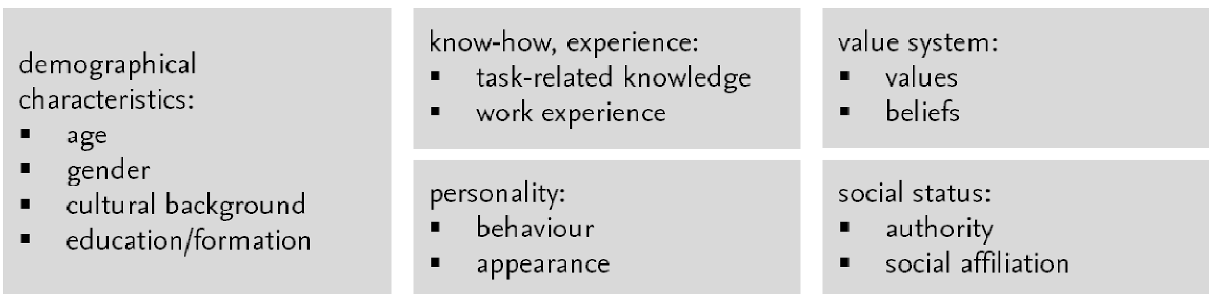


Figure 2-12 Knowledge, skills, abilities and other characteristics on the individual level of team characteristics as clustered by Nerdinger et al. (2014)

As collaborations across globally distributed teams increase in engineering design, diversity in general and particularly cultural background as well as a corresponding value system become more important. Teams tend to be more diverse from a cultural perspective. Thus, this aspect will be considered briefly. Hofstede (1983) defines culture as "collective mental programming: it is that part of our conditioning that we share with other members of our nation, region, or group but not with members of other nations, regions, or groups". He introduced four cultural dimensions being

- individualism versus collectivism,
- large or small power distance,
- strong or weak uncertainty avoidance,
- masculinity versus femininity.

Based on data collection in 50 countries, he clustered the countries regarding their indices in each dimension. As an example, the United States achieve a high score for individualism and a rather high value for masculinity, whereas the uncertainty avoidance is rather weak and the power distance small. Besides the national culture, other authors (Lee-Kelley & Sankey, 2008) mention the organisational and functional culture as important. Schumacher (2011) stresses the importance of cross-functional culture for virtual teams but emphasises not to forget about the other mentioned cultural aspects. Other authors dealing with national culture are Hall (1976) and Huntington (1993).

Revisiting the earlier presented IPO model, group-level factors are determined by the composition of the individuals described before. In this context, team cohesiveness, team size and diversity of the team are important aspects. Cultural diversity is not only seen as advantageous for creativity and team effectiveness according to Hertel et al. (2005). Simultaneously, cultural diversity hinders trust, cohesion building, decision-making and provokes conflicts (Kayworth & Leidner, 2000; Schumacher, 2011). Language problems are also mentioned as a key aspect of cross-cultural collaborations (Kayworth & Leidner, 2000).

Team size is seen as one of the determining variables for team processes. It affects team performance, effectiveness and other aspects like social loafing or cohesion (Hoegl, 2005). Various research on team size and its effects exists, see Hoegl (2005), Latané et al. (1979), Weiss and Hoegl (2016). With an increasing team size, the coordination and communication effort grows as well. At the same time, the cohesion of the team reduces in larger teams compared to smaller ones (Hoegl, 2005). In literature no precise values can be found for the optimal team size. Weiss and Hoegl (2016) use the term of relative team size meaning a team size adequate related to the task. A maximum team size of eight to ten persons is mentioned by Antoni (2014) which can be transferred to design teams that will apply a method. The minimum team size was mentioned earlier being at least three persons.

Both in autonomous or self-directed teams and less autonomous teams each team member takes a certain role within the team. A well-established model of team roles is the one of Belbin (1993). He defines nine roles: Resource Investigator, Teamworker, Co-ordinator, Plant, Monitor / Evaluator, Specialist, Shaper, Implementer and Completer / Finisher. Each role is described with strengths and weaknesses. For effective teamwork, a mixture of all roles is important. Thereby, one person can take more than one role. Often one personality consists of multiple roles or elements of roles.

Beside the mentioned characteristics of an individual, competencies[3] come more and more into the focus of research. According to Erpenbeck and von Rosenstiel (2007), competencies are dispositions for self-organised action. Thus, the difference between competencies and qualifications is the reference of competencies to a certain situation. Qualifications certify special knowledge or abilities at a point in time when the exam or test was done. Competencies enable the owner to cope with situations in an adequate manner. Hence, they are situation-related.

There are many different scholars with various definitions of competencies (Kauffeld, 2006b). In Anglo-American literature the Big Five, also known as five-factor model, are widely known and established. The model was built by a factor analysis of common descriptions of personality. The words used can be defined by five factors: openness to experience, conscientiousness, extraversion, agreeableness, and neuroticism, see Digman (1990). In German literature, especially in relation to engineering design, action-related competencies are divided into four superior competence facets. These facets are professional, social, methodological and self-competence, see Badke-Schaub and Frankenberger (2004), Kauffeld (2006b), as represented in Figure 2-13.

3 Moore et al. (2002) discuss the terms “competence“, “competency“ and “competencies“ since these terms are differently used in literature. In this thesis, there will be no differentiation. The terms are used interchangeably.

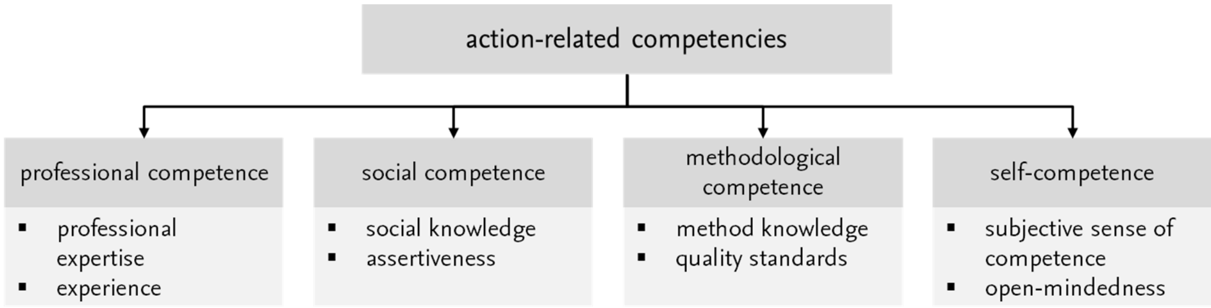


Figure 2-13 Action-related competencies divided into four competence facets according to Badke-Schaub & Frankenberger (2004)

Professional competence includes professional expertise, knowledge and experience. For engineering designers skills like abstraction abilities (Ponn, 2007), conceptualisation skills, calculation, reasoning and sketching (Andreasen et al., 2000) are important competencies. A detailed list of so-called “frames of understanding”, “professional abilities” and “technical competencies” for engineering designers can be found in Andreasen et al. (2000). Edwards et al. (2009) distinguish between “generic” and “specific competences” for engineering education. Beside professional competencies, they stress social and methodological aspects as relevant. In the competence model of Kauffeld (2006b), social competence comprises, for instance, social knowledge and assertiveness. Method knowledge and a feeling for quality standards are exemplary elements of methodological competence. The last facet, the self-competence, enables the owner to be open-minded and able to reflect on their own competencies (Kauffeld, 2006b).

In the context of design education and formation of engineers, Breitschuh et al. (2014) propose a five-dimension competence model. This model consists of the following dimensions: professional competence, methodological competence, strength of implementation, teamwork and creativity (Breitschuh et al., 2014). Creativity comprises the ability to generate a quantity of ideas with good quality. Teamwork considers the communication within the team, the ability to perform as a team and resource-planning. The strength of implementation deals with aspects like decision-making and selling the team’s ideas to others. An earlier competence model presented by Albers et al. (2009) considers professional, methodological and social competence as well as elaboration and creativity potential.

Although the models of Breitschuh et al. (2014) and Albers et al. (2009) were developed in particular for design teams, in the course of this thesis, the four competence facets will be used when dealing with competencies due to the commonness in previous work. In addition, the four competence facets are more general, and thus, easier to assess with common tools which is shown in the next section.

2.2.1.3 Assessment and diagnostic tools for teams

To determine the aforementioned characteristics and competencies of a team, assessment tools, tests or diagnostic tools are used. The history of testing or assessing begins according to Cohen et al. (2013) in France in 1905. The psychologist Alfred Binet developed a test to place school children in appropriate classes according to their knowledge and abilities. Later such tests were designed to identify suitable recruits for military service in the United States during World War I and II (Cohen et al., 2013).

Nowadays, there are various fields, in which assessment tools, team diagnoses and tests are applied. Cohen et al. (2013) distinguish between assessment of intelligence and personality in contrast to testing and assessment in action like clinical, counselling and neuropsychological assessment as well as assessment for careers and business. The latter includes career choices, selection of personnel, motivation and attitude tests as well as job satisfaction. The difference between testing and assessment is that tests try to deliver a "gauge, usually numerical in nature, with regard to an ability or attitude" whereas assessment tries "to answer a referral question, solve a problem, or arrive at a decision through the use of tools of evaluation" (Cohen et al., 2013). The term "diagnosis" in connection with the team is for instance introduced by Kauffeld (2001). Diagnosis means in this context identifying the characteristics of a team and how it interacts to derive team building measures or individual measures for personnel development.

Kauffeld (2001) names four main reasons to assess team or individual characteristics and competencies: selection, e.g. for eligibility tests, human resources development, procedures for individual interests like career counselling and competence assessment. As types for diagnosis or assessment the following examples can be found in literature: interviews (individual and group interviews), sensing meetings, standardised and non-standardised questionnaires, behavioural observation, critical incidents analysis, in generic tests, portfolios or role-play tests (Cohen et al., 2013; Kauffeld, 2001).

Kauffeld (2001) classifies existing assessment or diagnostic tools into process analytical and structure analytical procedures, see Table 2-4. Process analytical procedures focus on the objective reality using behavioural observation. Structure analytical procedures utilise questionnaires to obtain the subjective perception of a situation of a team member. The latter procedure is highly standardised, meaning a low time effort and low resource effort for the observer compared to process analytical procedures. However, structure analytical procedures mirror only a rough picture of a situation. When repetitively applied, memory effects and a high reactivity may be possible obstacles. Generally spoken, process analytical procedures reveal detailed information, even on micro-processes in the team, but need great time and resource effort even for trained coder. Structure analytical procedures, in contrast, represent a subjective rough picture perceived by an individual in a standardised manner (Kauffeld, 2001).

Table 2-4 Comparision of process analytical and structure analytical procedures for team assessment according to Kauffeld (2001)

	process analytical procedures	structure analytical procedures
focus	objective reality	subjective perception of team member
methodical approach	behavioural observation	questionnaire
advantages	▪ high information value ▪ attention to detail ▪ adequate representation of complex phenomenon ▪ no/low influences on subject matter ▪ recording of team structures via data aggregation	▪ high standardisation ▪ low time effort ▪ low resource effort ▪ easy to apply for long-term studies ▪ subjective perception (e.g. anger)
disadvantages	▪ low standardisation ▪ high time effort ▪ high resource effort ▪ coder training required	▪ rough picture ▪ high reactivity when repetitive applied ▪ memory effect when repetitive applied in quick succession ▪ no information on micro-processes

An example of a process analytical procedure is the ACT4TEAMS coding scheme (Kauffeld & Lehmann-Willenbrock, 2012). According to the four competence facets, the coding scheme classifies problem-focused, procedural, socioemotional and action-oriented statements. A situation, e.g. a meeting, is recorded via camera and audio and cut into small units of meaning. Each of these units is then coded with the help of the coding scheme by trained raters. As already critically considered, this approach to assess team characteristics is extensive but resource-consuming. Thus, it is not appropriate for the purpose of this thesis. A structure analytical procedure better fits the demands by offering an automated evaluation or the possibility to self-perception.

One of the structure analytical procedures already mentioned is the Belbin's Team-Role Self-Perception Inventory (BTRSPI). Belbin utilises eight statements giving nine response options. The respondent shall distribute ten points between the statements according to what they think fits their behaviour best (BELBIN Associates, 2013). The evaluation leads to the assignment of matching team roles (Resource Investigator, Teamworker, Co-ordinator, Plant, Monitor Evaluator, Specialist, Shaper, Implementer and Completer Finisher) (Belbin, 1993).

The complete Belbin test also includes an adjective rating list (BELBIN Associates, 2012) as they are used in other assessments as well, see Bender (2009). Besides, there are diverse tests or assessment and diagnostic tools measuring for instance the team climate (Team Climate Inventory) by Anderson and West (1994), learning styles (Learning Style Inventory) by Boyatzis and Kolb (1995) or competencies on the individual level (Competence-Reflection-Inventory) by Kauffeld and Henschel (2010). The last-named inventory, short C.R.I., is of interest for this thesis, as it provides a possibility to assess the four competence facets earlier described. To do so, it consists of 80 items clustered into the four competence facets. The professional competence includes fourteen positively formulated items. Social and methodological competences contain each nineteen positively and five negatively formulated items and the self-competence thirteen positively and five negatively formulated items. There are four subscales for the professional, six for the methodological, five for the social and four for the self-competence (Henschel, 2005; Kauffeld & Henschel, 2010). The C.R.I. is only available in German language and can be found in Kauffeld & Henschel (2010).

When critically reflecting on assessment and diagnostic tools and tests, it has to be mentioned that most tools are designed for a commercial purpose. Oftentimes a scientific validation is missing and the quality criteria are rarely completely fulfilled (Kauffeld, 2001). Quality criteria are reliability and validity (Cohen et al., 2013; Kauffeld, 2001; Van Der Vleuten, C. P., 1996) as well as objectivity, relevance, acceptance, and modifiability (Kauffeld, 2001) and costs (Van Der Vleuten, C. P., 1996). Due to the weaknesses of structure analytical procedures, it is recommended to use additional process analytical procedures to obtain valid and extensive information and to derive development measures for an individual or a team (Kauffeld, 2001).

2.2.2 Virtual teams in locally distributed environments

As introduced earlier, development tasks are more and more accomplished in specialised, multidisciplinary teams that work virtually or locally distributed together. The terms virtual, distributed and dispersed teams are often used interchangeably in literature (Chamakiotis et al., 2010). The meaning of these teams is, compared to traditional or face-to-face teams, that they collaborate locally, temporally and/or culturally distributed. Often the term "global (product development) teams" is used to name such teams. Early research on this topic started to investigate the differences between virtual and face-to-face teams, c.f. (Archer, 1990; Hollingshead et al., 1993). More recent research extenuates the strict differentiation and introduces the term of virtualness or virtuality. Griffith et al. (2003) make use of the three dimensions of virtualness: level of technological support, physical distance, and percentage of time spent on common task. Thus, a local team that frequently uses technology for communication and coordination spending most of the time on the common task has a higher dimension of virtualness than a locally distributed team, communicating only face-to-face in rarely upcoming meetings and only working partly on the common task. Kirkman and Mathieu (2005) extend the model of virtuality of Griffith et al. by introducing two new dimensions: the "extent of using virtual tools" remains and the "amount of informational value provided by such tools" as well as the "synchronicity of team member virtual interaction" is added. There are other models in literature that have in common the definition of a "team virtuality" instead of a strict distinction of virtual and traditional team. Nevertheless, the terms virtual and distributed team are used in this thesis interchangeably for all teams except for traditional face-to-face meetings. Schumacher (2011) gives a detailed overview of different definitions of virtual teams. She proposes a scheme with similarities and differences of virtual and traditional teams as shown in Figure 2-14. The understanding of virtual teams is defined as Schumacher (2011) does:

> *"A virtual team consists of individuals who are temporally, geographically, organisationally and/ or culturally dispersed and act interdependently through technology to achieve a common goal. A virtual team is embedded in an organisational setting."*

According to Duarte and Snyeder (2006) there are different types of virtual teams:

- virtual network team,
- virtual parallel team,
- virtual project/product development team,
- virtual work, functional, or production team,
- virtual service team,
- virtual management team,
- virtual action team.

The difference is seen in the temporal, local and task distribution, in the duration of collaboration, the change of team members and the general objective of the team (management, action etc.). In this thesis, mainly project/product development teams are focussed.

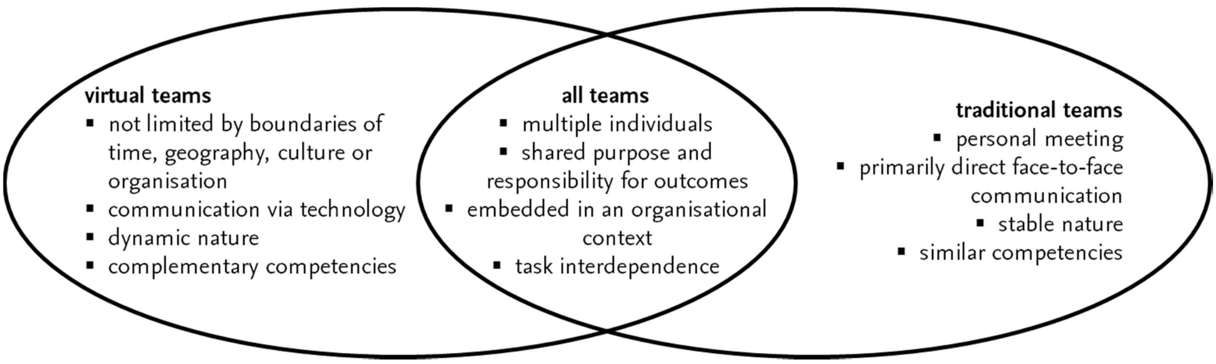


Figure 2-14 Similarities and differences of virtual and traditional teams as proposed by Schumacher (2011)

2.2.2.1 Potentials and challenges

As introduced earlier, today's product development transforms to more global environments. Thus, persons from all over the world collaborate. The reasons are various. The complexity of modern products increases and thus multiple disciplines are oftentimes involved in the product development process, e.g. from mechanics, electronics and software. Subsequently, experts from different disciplines are required to successfully develop a new product or a variant of an existing product. The challenge is bringing together all subsystems and components to build the complete system (Bavendiek et al., 2016a). In this context, people and whole companies can be seen as knowledge carriers that have to be brought together (Vietor et al., 2015). Hence, a main driver or potential for collaborative design or virtual teams is the sourcing of different know-how. There are multiple strategies like the integration of external knowledge, the systematic distribution of knowledge or the concentration on core competencies (Gaul, 2001). In addition, the flexibility to share and use manpower as well as production capacity of dispersed sites plays an important role for the introduction of virtual (production) teams. Further potentials for the use of virtual teams are according to Gaul (2001) the proximity to customers, the systematic usage of different mindsets across the cultures, the reduction of time and costs, local content as well as outsourcing strategies. Larsson et al. (2003) compare potentials and challenges of virtual teamwork using consistent topics like time differences, cultural differences, market closeness, proximity, awareness, communication latency, and mobility and heterogeneity. The comparison of potentials and challenges is summarized in Table 2-5.

Against the background of an increasing digitalisation, these potentials can be more and more used. New technologies enable sharing of knowledge, working virtually together, exchanging and representing information over distances (Bavendiek et al., 2016a). However, the virtual collaboration poses new challenges for team members. Local distribution, time differences and various cultures involved demand additional competencies, e.g. intercultural competencies and methodological competencies for new technologies like virtual reality (VR). The missing proximity to colleagues reduces the direct contact and thus informal communication, essential for team building (Larsson et al., 2003).

Table 2-5 Potentials and challenges of virtual collaborations as listed by Larsson et al. (2003)

	challenges	potentials
time differences	▪ coordination of work is often difficult when different time zones ▪ small overlap of working hours	▪ use of a global work force allows for 24-hour design ▪ accelerates development cycles by combining teams from different time zones
cultural differences	▪ different countries and cultures lead to different ways of talking, being and acting ▪ successful collaboration depends ability to build trust, rapport, and respect to bridge the differences ▪ high potential for conflict ▪ managing conflicts becomes a key factor for success	▪ differences in culture, education, organization, and work methods allow for multiple perspectives on ideas ▪ diversity in all forms will add to the creative power of the global team
market closeness		▪ closer and stronger relationships with customers, distributors and retailers
proximity	▪ small physical distance reduces daily contact and informal communication between collocated team ▪ when physical distance increases, the "information richness" in communication decreases	▪ extra effort of "globalizing local knowledge" could be a competitive advantage for distributed companies ▪ better mix of individual and collaborative work
awareness	▪ local teams exchange information, monitor progress, and learn about what others are doing (awareness about people and awareness about process) → maintaining awareness across distance is crucial for successful collaboration	
communi-cation latency	▪ delay in the resolution of work due to difficulties to find the right person, initiate contact, and discuss possible solutions ▪ less fluid flow of ideas	
mobility and hetero-geneity	▪ difficulties to initiate contact with people ▪ difficulties to communicate via a wide range of technical platforms (e.g. laptops, PDAs, mobile phones) and different operating systems and applications	▪ no longer dependent on the availability of a single physical space, the co-presence of team members, or a specific technical platform ▪ product development becomes global and mobile

In contrast, the communication and coordination in engineering design teams increase in general. Schleidt and Eigner (2010) found a decrease from 50 % to 25 % of professional tasks in daily work of an engineer in favour of an increase of communication and coordination tasks (between 2000 and 2006). Nevertheless, Straus (1996) observed that teams using technologies for communication utilise in average half the number of words for their communication than face-to-face teams. The reason is seen in the higher effort to communicate text-based compared to verbally. An effect of the reduced communication is the neglect of the interpersonal level. This, in turn, leads to a negative effect on team variables like trust and cohesion (Kauffeld et al., 2016). Early research work has already dealt with the selection of appropriate media for communication in virtual teams. Daft and Lengel (1986) propose the media-richness-theory bringing into relation the complexity of the communication task and the media richness. Media richness is the amount of information transferable via certain media. A telephone call, for instance, has a lower media richness than a videoconference, in which video is added to audio communication. The correlation of media richness and communication task is presented in Figure 2-15 illustrating the challenge of an effective communication in virtual teams.

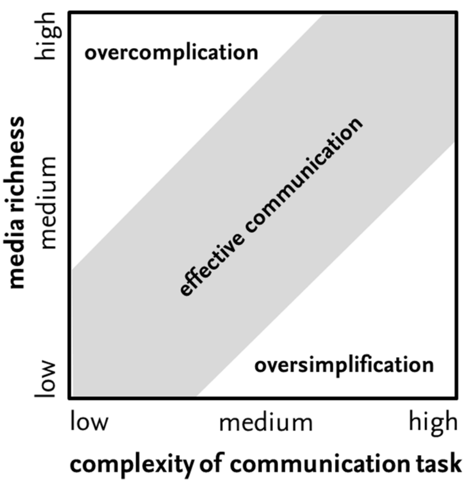


Figure 2-15 Media-richness-theory of Daft and Lengel (1986) according to the representation of von Rosenstiel et al. (1999)

Besides the challenge to cope with the more complex communication situations, organisational structures have to be and are adapted to more flexible working hours and places, which results in a demand for mobility (Bavendiek et al., 2016a; Larsson et al., 2003). On the one hand, this offers great potential for the team members in a virtual team to become more flexible and independent from physical spaces. On the other hand, the flexibility and mobility hinder the easy contact with other team members and lead to a dependence on technologies (Larsson et al., 2003). Grieb and Lindemann (2005) focus on the challenges with regard to the technologies used. They noticed in a survey among engineering practitioners that the virtual collaboration could be highly enhanced when the technologies are improved. Practitioners asked mainly for shared applications and VR-media. Though, the data protection and security of knowledge remain the major challenges (Grieb & Lindemann, 2005).

Especially with regard to teamwork and the organisational context, Duarte and Snyeder (2006) postulate the following critical success factors for virtual teams:

- human resource policies,
- training and on-the-job education and development,
- standard organisational and team process,
- use of electronic collaboration and communication technology,
- organisational culture,
- leadership support for virtual teams,
- team leader and team member competencies.

To enable a successful virtual team, training and other support have to be provided by the organisation. The appropriate training of team leaders in virtual teams is seen of high relevance as well (Duarte & Snyeder, 2006).

2.2.2.2 Characteristics of virtual teams

A differentiation and comparison of virtual to traditional teams as proposed by Schumacher (2011) was shown before (see Figure 2-14). She extends the list of virtual team characteristics presenting a list of eleven criteria (see Table 2-6, right column). Besides the number of team members, geographical, time, organisational and cultural boundaries are named. Except for the cultural boundaries, Anderl et al. (1999) and Gaul (2001) present the same characteristics which are in total fifteen (see Table 2-6, left column). The intensity of the collaboration corresponds to the contractual situation listed by Schumacher (2011). The competencies required in virtual teams are also named in both lists.

The remaining characteristics of Anderl et al. differ from the criteria of Schumacher. Additional characteristics are language, size of company, data access, capacity, tool and method compatibility (Anderl et al., 1999), whereas Schumacher (2011) adds kind, discipline and position in the product life cycle of the team members as well as the duration of the collaboration.

Table 2-6 Overview of collaboration characteristics from different authors

	Gaul (2001) / Anderl et al. (1999)	Schleidt (2009), Schleidt and Eigner (2010)	Schumacher (2011)
characteristics, criteria, dimensions	number of partners (2, >2, very high)		number of team members (bilateral, multilateral)
	location (different room, location, country)	local distribution (international, national, regional)	geographical boundaries (international, national, regional, departmental)
	time (sequential, parallel, mixed)	time zones (1, 2, 3 and more)	time boundaries (1, 2, >2 different time zones)
	language (same, different)		
	organisation (same organisational unit, same company, different company)		organisational boundaries (intra-organisational, inter-organisational)
	size of company (large, middle sized, small company)		
	intensity of collaboration (integrated, loose combination)	project organisation (project management and structure)	contractual situation (contractual, non-contractual relation)
	distribution of components (yes, no)		
	distribution of tasks (yes, no)		
	number of interfaces (high, medium, small)		
			kind of team members (service providers, suppliers, end users, etc.)
	data access (possible, not possible)		
	competence (high, medium, small)		competencies of team members (complementary competencies)
	capacity (sufficient, insufficient)		
	tool compatibility (yes, no)		
	compatibility of methods (yes, no)		
			duration (long- or middle-term, temporary or permanent, dynamic nature)
		diversity (intercultural, interdisciplinary and / or interfunctional composition)	cultural boundaries (1, 2, >2 different cultures)
			disciplines of team members (same discipline, multidisciplinary)
			position of team members according to the product life cycle (horizontal=different phases, vertical=same phases)
		interaction and communication (face-to-face, via media)	

The overview also contains the dimensions of collaborations used by Schleidt and Eigner (2010) and Schleidt (2009) to describe the circumstances of virtual teamwork. Their focus is the correlation to required competencies due to changed working conditions. The five presented dimensions match some of the characteristics and criteria of Anderl et al. (1999) and Schumacher (2011). Local distribution and time zones can be directly compared to the corresponding aspects of the other authors. Project organisation comprises a wide field and is comparable – amongst others – to the aspects distribution of tasks and of components as well as number of interfaces of Anderl et al. (1999). The dimension of diversity includes culture, discipline and function of the team members. This aspect is similar to the more detailed consideration of Schumacher (2011). Finally, Schleidt and Eigner (2010) introduce the dimension of interaction and communication. This comprises mainly the kind of collaboration (face-to-face or mainly media-based).

Competencies for virtual collaborations

Beside the characteristics to describe virtual teams, many authors state that additional competencies compared to traditional teams are required, e.g. Berry (2011), Duarte and Snyeder (2006), Kauffeld et al. (2016). Hertel et al. (2006) assume that the competencies needed within a traditional team apply also for virtual teams. Telecooperation competence is additionally required. Hertel et al. (2006) divide the knowledge needed for telecooperation competence into self-management, interpersonal trust and intercultural KSAs. A detailed overview on competencies needed in virtual collaborations of various members from different companies or freelancers is presented by Auffermann et al. (2007). They determine fourteen fields of competencies like trust competence, work-life competence or coopetition (combination of cooperation and competition) competence when working together with competing enterprises. Further authors generally dealing with virtual teams are for instance Getha-Taylor (2008) or Shin (2004). Not all of these competencies are directly transferable to engineering design context. Other authors focus on cross-enterprise and thus virtual engineering design teams. Schleidt (2009), for instance, obtained a set of competencies for cross-enterprise collaborations in engineering design from interviews and surveys, which is illustrated in Figure 2-16.

Figure 2-16 Competencies required additionally in virtual collaborations according to Schleidt (2009)

Schleidt (2009) correlates these competencies to the earlier introduced dimensions of collaboration to evaluate the team members and their need for personal development within the so-called House of Engineering Competencies (Schleidt & Eigner, 2010).

The need to prepare engineers for global collaborations is also seen in design education. Lohmann et al. (2011) present a higher educational program considering competencies for globally working teams. They focus mainly on three aspects:

- broader multidisciplinary knowledge (global socio-economic and political systems, international commerce and world markets, environmental systems and innovation),
- interpersonal skills in global collaborations,
- ability to live and work comportably in transnational engineering environments.

The three mentioned aspects set the framework for a study program addressing the so-called global competencies in engineers (Lohmann et al., 2011).

2.2.2.3 Support of virtual teams

As the virtual collaboration increases, research focuses on various aspects to understand and to subsequently support virtual teams in their daily work. To classify existing work, Bavendiek et al. (2016a) proposed the consideration of three views on collaborative design. These views comprise a process, technical-methodical and personal view. The views and possible elements are illustrated in Figure 2-17.

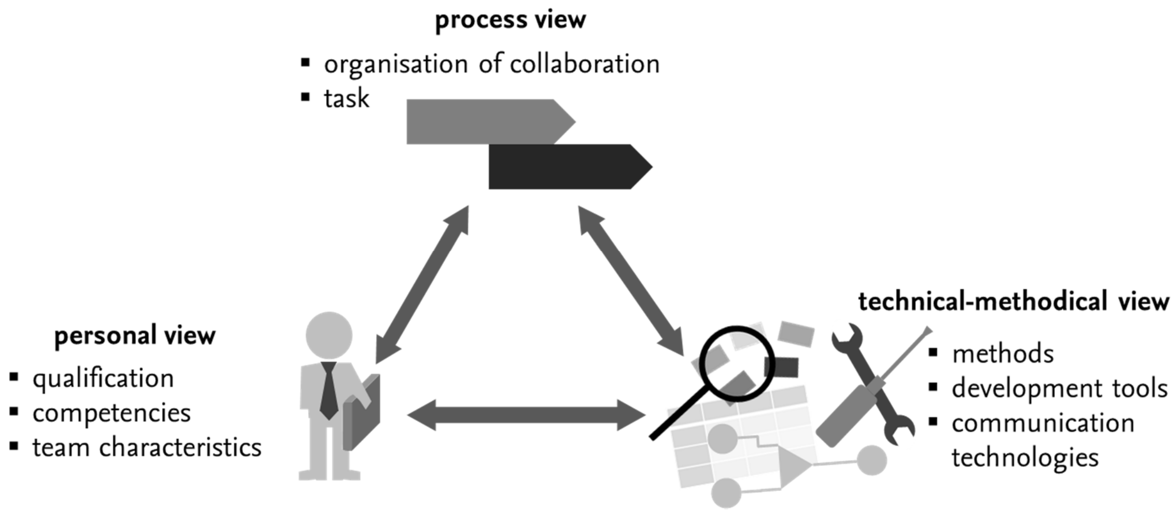


Figure 2-17 Three views on collaborative design and virtual teamwork according to Bavendiek, Inkermann et al. (2017)

Later work (Bavendiek, Inkermann et al., 2017) uses these views as observation views on different layers to describe the interrelations of modelling and support from the different views. Some of the support for virtual teams was already presented, e.g. the House of Engineering Competencies of Schleidt (2009) or the media-richness-theory of Daft and Lengel (1986). Since this thesis aims to develop a concept for a tool linking the personal and technical-methodical view in terms of matching methods to team aspects, some existing approaches of support from the corresponding views are presented in the following.

From the personal view, the virtual qualification coach (VICO) developed by Auffermann et al. (2007) can be mentioned. This tool offers the possibility to identify missing competencies for virtual teams on an individual level. Potential development measurements are proposed (Auffermann et al., 2007). Hertel et al. (2005) present the Virtual Team Competency Inventory (VTCI), which is an online-based tool to select and place members in virtual teams. The PEGASE tool considers knowledge, activity, autonomy and quality of different persons within an enterprise (Rose et al., 2009). A tool, not specially developed for virtual teams but originally for handcraft is the Kompetenz-Navi (competency navigator), a web-based and adaptive tool for competency assessment (Kortsch et al., 2018). Future work will be done to develop a special competence navigator for virtual teams, e.g. Paulsen et al. (2018) and Bavendiek et al. (2018). Schumacher (2011) proposed a scheme that considers the life cycle of new product development, project management and team development of virtual teams.

From the technical-methodical view, mainly research work dealing with methods is of interest. An overview of method provision approaches was already given in Section 2.1.3. Up to now, there are few approaches including the personal view in method provision. First propositions were made by Bavendiek et al. (2014) and Bavendiek et al. (2016a).

Focussing on communication, coordination and collaboration technologies, there is a wide field of research on computer-supported collaborative work (CSCW). Robin et al. (2007), for instance, address the exchange of knowledge and information in their research resulting in the IPPOP software tool. Martinec and Pavkovic (2014) combine diagrams originating in the development process with communication. Their purpose is to visualise traces of documents for transparency. Similar to the media-richness-theory, Gaul (2001) proposes the House of Communication. This correlation matrix helps to identify adequate communication technologies for communication tasks. Due to the importance of informal communication in teamwork, Törlind and Larsson (2002) introduce a Contact Portal being an instant messenger in virtual teams. They found good results for improving the virtual collaboration.

2.3 Knowledge transfer and training in design education and practice

According to Lutters et al. (2014) the user of methods and tools, the level of expertise with methods but also generally and training have a direct influence on the quality, time and cost of the development of a product. After considering user and their experience in terms of the team, this section focuses on the training of engineering designers with regard to methods. To do so, first basics of knowledge transfer as well as general didactical concepts, which are mainly used in education, will be presented. Second, concepts especially addressing method knowledge transfer and training are described. Thereby, a differentiation between design education at universities and higher education facilities and training in practice will be made.

2.3.1 Introduction to knowledge transfer

The term *knowledge* is defined as "facts, information and skills acquired through experience or education; the theoretical or practical understanding of a subject" (Oxford Dictionaries, 2018a). In the context of design education focussing on methods and tools, knowledge in this field is, for instance, knowledge about the methodical procedures in design, choice of methods and execution of methods (Geis, Birkhofer et al., 2008). Subsequently, knowledge transfer is the theoretical and practical training of this knowledge. Training is generally defined as "the action of teaching a person or animal a particular skill or type of behaviour" (Oxford Dictionaries, 2018b). Further definitions with regard to education, training and methods will be given in chapter 5.

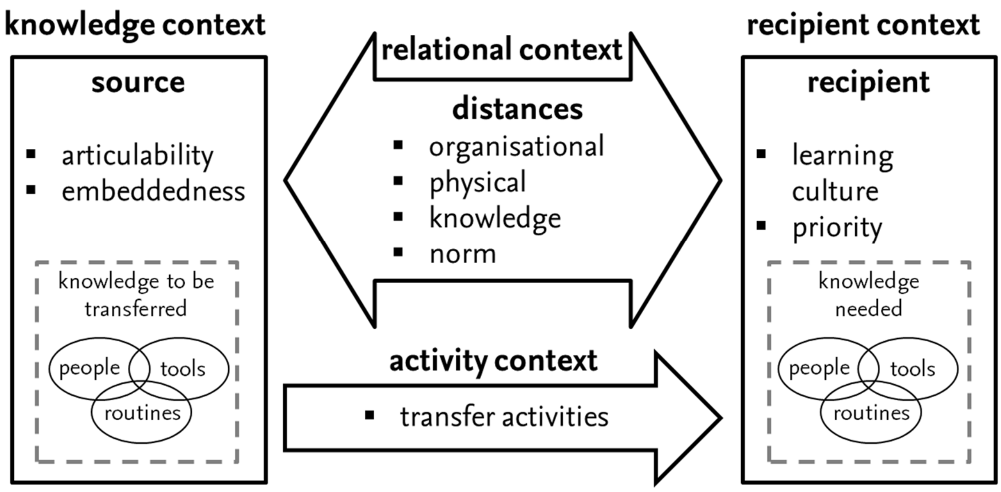


Figure 2-18 Research model for knowledge transfer according to Cummings and Teng (2003)

When considering knowledge transfer in general, various aspects originating different contexts should be considered. Cummings and Teng (2003) reviewed literature on knowledge transfer including organisation internal transfer but also transfer from one organisation to another, thus, external transfer. Organisations can be in this context, for instance, companies or research institutions but also individuals. Cummings and Teng (2003) clustered the aspects found in the four groups knowledge, relational, activity and recipient context as it is presented in Figure 2-18. Among the knowledge context, they name articulability and embeddedness, among the recipient context learning culture and priority. The activity context describes the activities done to perfom the transfer whereas the relational context consideres distances between source and recipient of knowledge. These distances can be of organisational or physical nature. Other types can be distances in knowledge and norms. The underlying model is general in the way that it applies to education as well as to transfer knowledge from research to practice or vice versa. Though, Cummings and Teng (2003) focus on the latter.

Focussing on the knowledge transfer from research to practice, there are various channels cogitable. Brennenraedts et al. (2006) summarized the following list from previous literature from the viewpoint of research:

- publications,
- participation in conference and professional networks and boards,
- mobility of people,
- other informal contacts and networks,
- cooperation in research and development,
- sharing of facilities,
- cooperation in education,
- contact research and advisement,
- intellectual property rights,
- spin-offs and entrepreneurship.

For each of these channels, they list manifold transfer possibilities for detailing purpose. More than 60 persons from research (professors, research staff and PhD students) rated these detailed channels regarding their importance. Most important are conferences and workshops as well as refereed scientific journals or books, directly followed by joint research and development projects with industry partners. Other important channels are networks based on friendship and presentations at industry partners (Brennenraedts et al., 2006).

Considering the viewpoint of practice, a study from 1998 conducted in German industries regarding knowledge management including amongst other factors knowledge transfer gains insights (Bullinger et al., 1998). Training followed by cooperation with customers are mentioned as most applied measures for knowledge acquisition. Further means are research in professional journals, competitor analysis and cooperations with suppliers. The fewest used measure is the cooperation with universities (Bullinger et al., 1998).

Concerning the sharing of knowledge, systematic training and self dependent knowledge transfer are indicated to be most important. The transfer of methods as well as of negative experiences is also seen relevant for a successful knowledge sharing (Bullinger et al., 1998).

Beside knowledge acquisition and sharing, Bullinger et al. (1998) name six further elements of knowledge management. These are objectives, evaluation, usage, conservation, development and identification of knowledge.

2.3.2 General didactical concepts

Education and learning processes can be seen as part of knowledge transfer where the knowledge is transferred from the teacher to the learner. Like on knowledge transfer processes, there are many different influences on the learning and education process like the motivation of the learner, success of the learning process and feedback from the teacher or trainer. Geis et al. (2010) present some of these influencing factors that have to be considered when preparing the didactical concept and materials (see Figure 2-19).

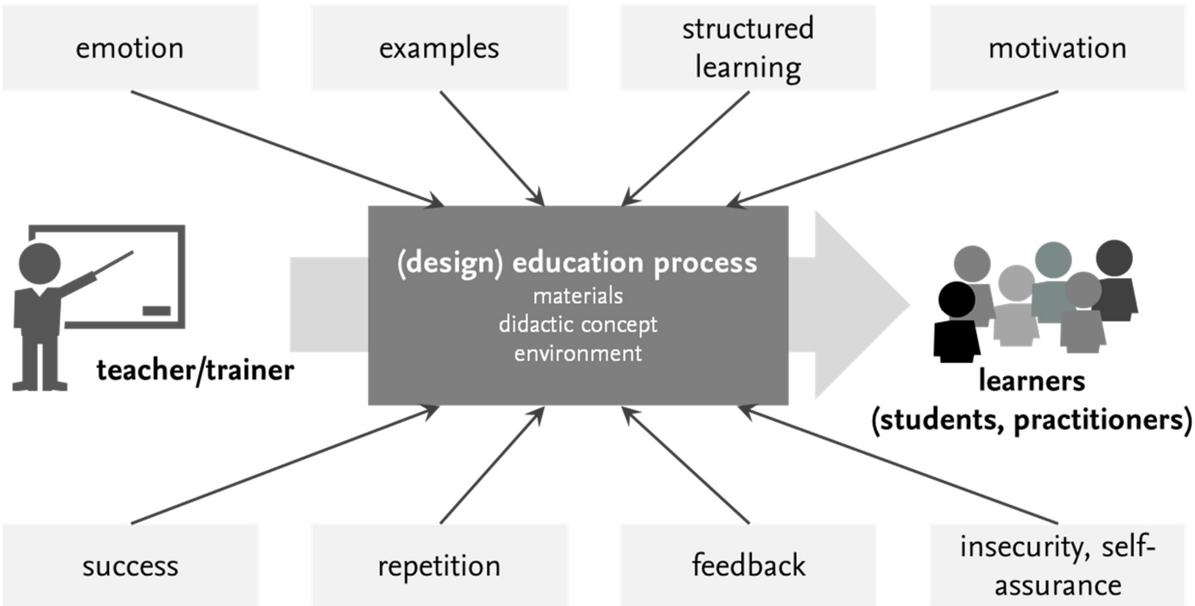


Figure 2-19 Influences on design education processes according to Geis et al. (2010)

The learning success of the learner is then depending on the four following aspects (Lenhart & Birkhofer, 2007):

- cognitive processing,
- learner characteristics,
- instructional goals,
- instructional material.

To have a closer look at the cognitive processing and the learner characteristics, the following section deals with types of learners and learning theories. Instructional goals and material will be addressed subsequently in the sections on education theories, on the structure of educational courses and training as well as on media and formats for education and training.

2.3.2.1 Types of learners

In the 1970s, the German Fredric Vester published his theory of types of learners meaning different ways of perceiving information. He distinguished four types being visual, aural, kinesthetic and intellectual (Vester, 1998). His theory was much discussed due to the discrepance between the three types based on the method of perception and the intellectual type. It was not clearly argued on how the intellectual type perceives the information, e.g. (Looss, 2001). In English literature, Neil Fleming presented the VARK (visual, aural, read/write and kinesthetic) model and a corresponding test in the 1980s. Instead of the intellectual type, Fleming introduced the read/write type (Fleming & Bonwell, 2005). The four types are summarised in Figure 2-20 on the left-hand side.

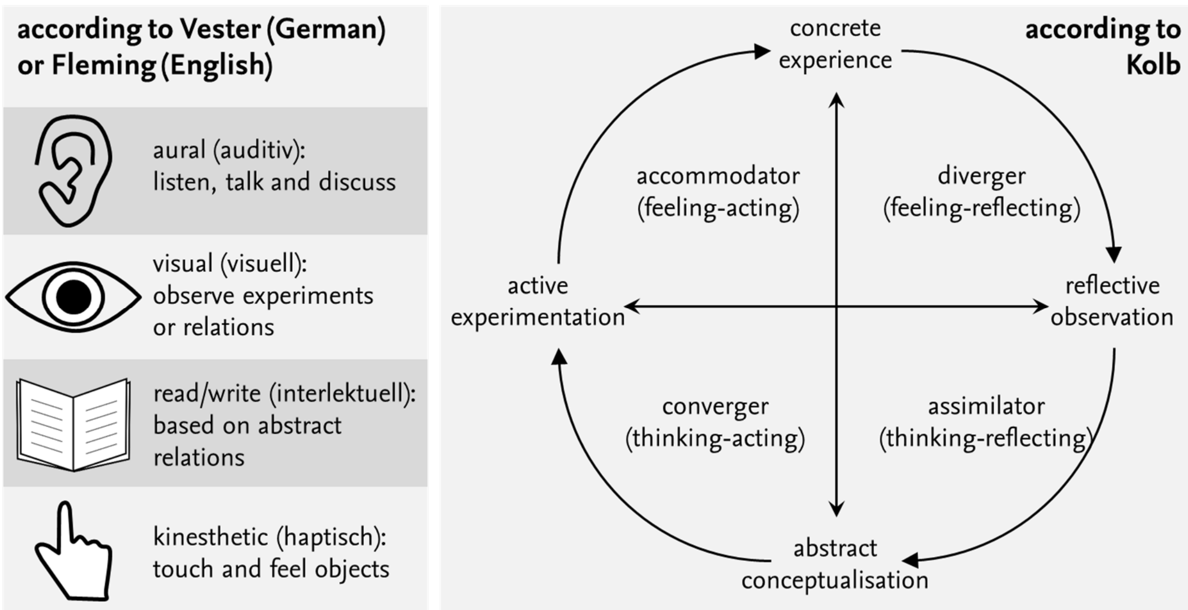


Figure 2-20 Types of learners according to Vester (1998) respectively Fleming & Bonwell (2005) (left) and according to Kolb & Kolb (2005) (right)

On the right-hand side, the four types of learners according to Kolb are presented. Kolb uses the Experiential Learning Cycle from active experimentation, concrete experience, and reflective observation to abstract conceptualisation to describe the occurrences of human learning. Putting axes into the cycle, "two dialectically related modes of grasping experience" (ordinate) and "two dialectically related modes of transforming experience" (abscissa) arise (Kolb & Kolb, 2005). The emerging quadrants can be described with four different types of learners: the accommodator between active experimentation and concrete experience, the diverger between concrete experience and reflective observation, the assimilator between reflective observation and abstract conceptualisation, and the converger between abstract conceptualisation and active experimentation. Similar to the VARK test of Fleming, Kolb developed the so-called Learning Style Inventory (LSI) as a test to determine the predominant learner's type (Kolb & Kolb, 2005).

Another approach is proposed by Gagné (1984) who describes five categories of learning. These categories are verbal information (learning the alphabet), intellectual skills (addition and subtraction), cognitive strategies (exploring the action of a magnet), attitudes (how one experiences driving dynamics) and motor skills (tighten a screw).

A special learning type classification for engineering education was presented by Felder and Silverman (1988). They used previous work on types of learners and finally differentiate five preferred learning styles:

- perception (sensory, intuitive),
- input (visual, auditory, revised version: visual, verbal),
- organisation (inductive, deductive, revised version: completely deleted style),
- processing (active, passive),
- understanding (sequential, global).

Felder and Silverman offer corresponding teaching styles to the mentioned learning styles being concrete and abstract content, visual and verbal presentation, inductive and deductive organisation, active and passive student participation and sequential and global perspectives (Felder & Silverman, 1988).

2.3.2.2 Learning theories

Learning theories deal with the way how a learner perceives new information. Early scientists saw the learner as a passive role reacting to conditions and stimuli from the environment. This theory is known as behaviourism. Key elements of behaviourism are "the stimulus, the response and the association between the two" (Ertmer & Newby, 1993). The focus is on the objectively observable behaviours (Cooper, 1993). In the late 1950s, scientists focused on the brain as the enabler of the internal learning processes. They investigated how information is received, stored and retrieved by the human's brain. This theory is called cognitivism (Ertmer & Newby, 1993). In the 1990s, a new wave of those questioning the basic assumptions of behaviourism and cognitivism (the external world is real) came up. Scientists started to consider that learners construct their own world, their own meaning of things learnt. The learner includes their past and current knowledge, social interactions and motivations in the learning process resulting in an active process conducted by the learner (Cooper, 1993; Ertmer & Newby, 1993).

To demonstrate the different learning theories, Figure 2-21 gives examples of learning content connected to engineering context. For each knowledge type (factual, applied and instructional knowledge), the corresponding learning theory is linked.

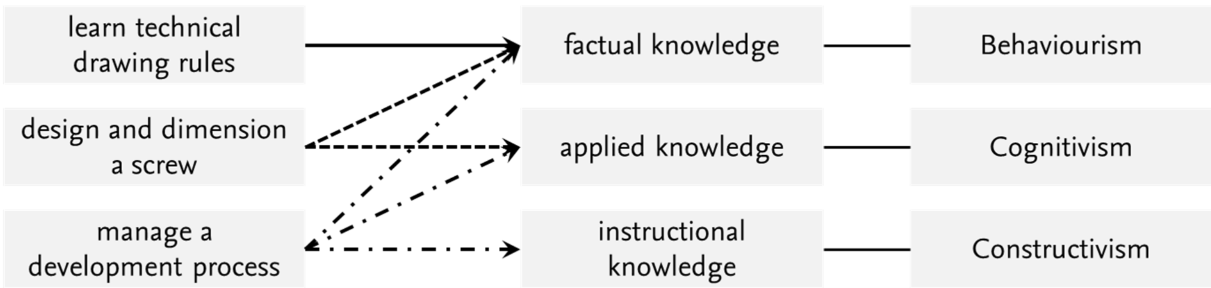


Figure 2-21 Examples for behaviourism, cognitivism and constructivism in engineering context

Current research deals with learning theories in the digital age. Siemens (2005) calls this theory connectivism. "Connectivism is the thesis that knowledge is distributed across a network of connections, and therefore that learning consists of the ability to construct and traverse those networks." (Downes, 2012) The learner learns self-directed using the networks, e.g. content sources, people etc. (Siemens, 2005).

2.3.2.3 Education theories

In contrast to learning theories, education theories focus on the way how knowledge can be taught. One of the most cited and acknowledged theories is the taxonomy of educational objectives postulated by Bloom et al. (1956). Bloom's taxonomy distinguishes six classes of educational objectives building up on each other. These classes are knowledge, comprehension, application, analysis, synthesis and evaluation (see Figure 2-22). Knowledge can be divided into knowledge of specifics, knowledge of ways and means of dealing with specifics, and knowledge of universals and abstraction in the field. Comprehension comprises translation, interpretation and extrapolation. Application means applying the before-learnt. Analysis can be analysis of elements, relationships or of organisational principles. Synthesis comprises all kind of combining or developing systems, structures or plans. This might be the production of unique communication, of a plan or a proposed set of operations or the derivation of a set of abstract relations. Evaluation is the judgement of internal evidence or external criteria (Bloom et al., 1956).

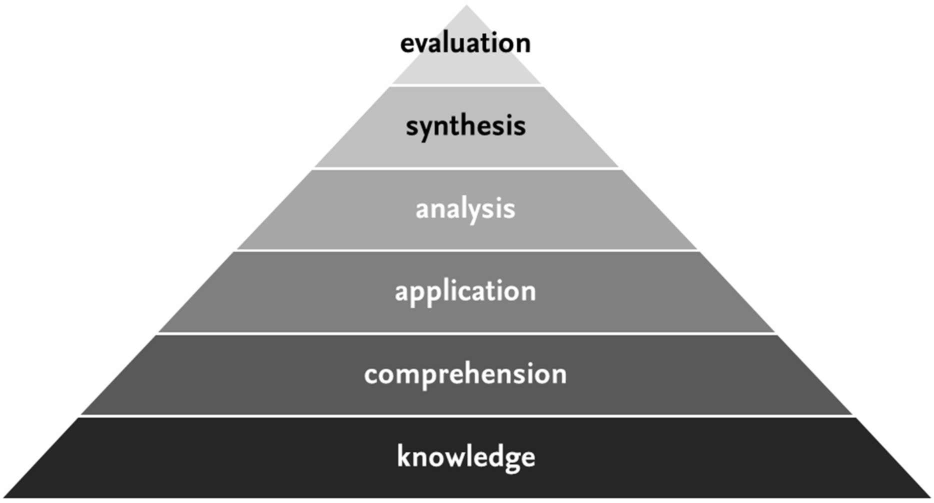


Figure 2-22 Taxonomy of educational objectives according to Bloom et al. (1956)

The Bologna Working Group on Qualifications Frameworks (2005) supports a similar qualification framework to standardise European education systems. According to the Dublin descriptors, the following elements are used to describe qualification goals of Bologna cycles (Bologna Working Group on Qualifications Frameworks, 2005):

- knowledge and understanding,
- applying knowledge and understanding,
- making judgements,
- communication skills,
- learning skills.

These education theories build the framework on how to qualify learners. They can be applied for the design of complete courses.

2.3.2.4 Structure of educational courses and trainings

In this thesis, the term course is used for teaching within design education whereas the term training is refered to teaching within (industry) workshops. Both can consist of multiple units being normally called classes in education and workshops in industry context.

For the design of single classes (or workshops), two types of structure can be differentiated: vertical and horizontal structure of classes. Vertical structures address content meaning that a class should consist of an introduction, a main part and a summary or conclusion. Horizontal structures define the teaching methods, media and formats like groupwork, individual learning, presentation, discussion, exercises (Dummann et al., 2007).

Gagné et al. (2004) propose an approach, which is an architecture for successful workshops or classes, which are called "Nine Events of Instruction". These events are sequentially built on each other and are meant to be a holistic concept to train or teach the attending persons. The "Nine Events of Instruction" consist of the following elements to structure a class or workshop (Gagné et al., 2004):

- gain the attention of the participants (e.g. by giving visual stimuli),
- inform the learner about objectives (e.g. by writing training objectives on a board),
- stimulate recall of prior learning (e.g. by asking questions about prior experiences),
- present (new) content/material (e.g. by using a presentation or movie),
- provide learning guidance (e.g. by giving examples or case studies),
- elicit performance (practice of new skill or behavior, e.g. in a design task),
- provide feedback (e.g. by giving additional answers and guidance),
- assess performance (possibility of a post-test for participants),
- enhance retention transfer (e.g. by handouts, online aids or follow-up sheets).

Further training concepts, especially for method transfer and training, will be presented in Section 2.3.3.

2.3.2.5 Media and formats in education and training

Media can support education and training. Media can be added to different formats of education like slides can support a presentation. There are various different types of media ranging from classical ones like literature and lecture notes to videos and software tools. Laboratories and team projects are possible teaching formats besides traditional lectures. An overview of the diversity of media and formats is given in Figure 2-23.

Beside selecting existing media for the course or training, it is possible to create own material. To do so, it is helpful to consider the target group as described by Lenhart and Birkhofer (2007). Furthermore, documents should be created comprehensible. Langer et al. (2015) give advice on how to make mainly text documents understandable. They highlight four aspects:

- simplicity: diction, structure of sentences and phrasing,
- structure: general structure by paragraphs, reasonable order of information,
- conciseness: reasonable ratio of length and information content,
- exhilarating supplements: using story, motivating examples, humorous components, etc..

Although mainly designed for texts, these four aspects can be transferred to other training media like videos or exercises.

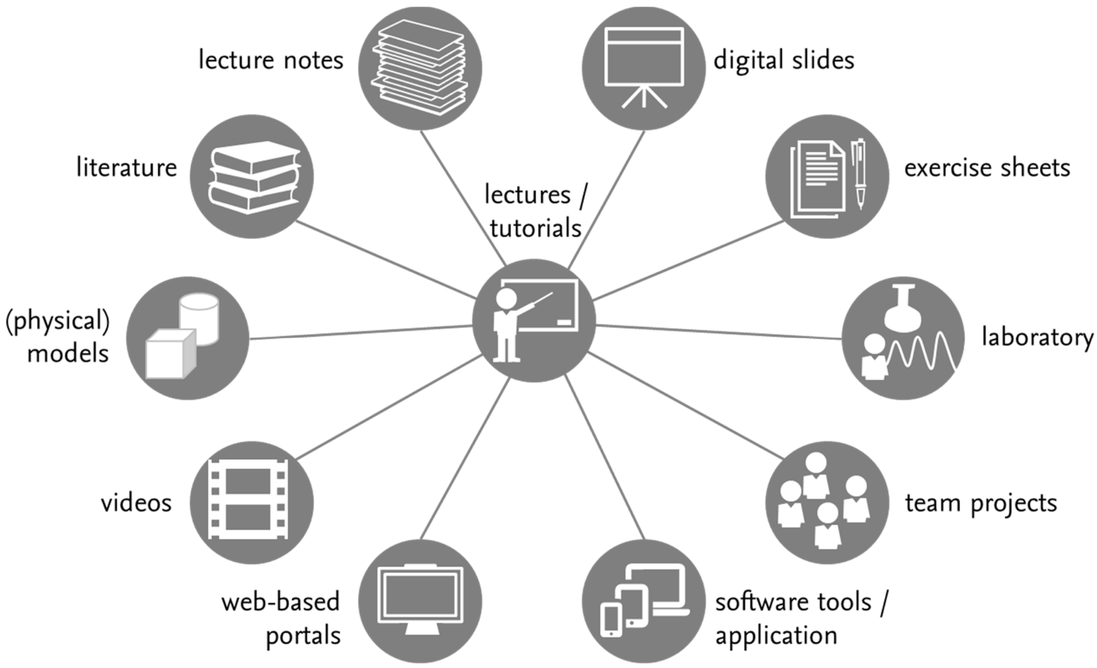


Figure 2-23 Different media and formats for education and training according to Dummann et al. (2007)

Explanatory videos

Explanatory videos will be considered as special media. These videos are defined as "short animated videos to explain a complex issue" (Reiss et al., 2017). Videos are an increasingly used medium to explain different topics in short time. The advantage of videos compared to text, audio files or pictures only is the combination of both visual and aural perception for the audience. Chirumalla et al. (2015), for instance, observed that videos in comparison to drawings, text only, and text and drawings combined was better rated and led to a better performance of the test groups accomplishing a procedural task using different media instructions. Thus, the main elements of a good designed explanatory video are (1) pictures and animations for visual information transfer, (2) an audio script and background music for aural information transfer and (3) a simple and relevant story for giving the structure (Reiss et al., 2017).

Explanatory videos become more and more popular. Websites like YouTube (2005) provide a great number of explanatory videos and channels producing such videos on diverse topics, e.g. explainity (2011) with more than 100 videos and more than 90.000 subscribers (as in January 2018). The areas of application for explanatory videos are wide, for instance, explaining the world, advertising through social media, helping other people or presenting new ideas, e.g. Biswas (2014).

Modern formats for education based on media

The popularity of videos and other online material, often called e-learning material, are the response to a changing environment influencing the daily work but also the way of consuming information and thus the formats of education. In Croatia, for instance, a complete e-learning environment in the context of engineering design was introduced (Marjanovic & Storga, 2011). Another approach using e-galleries and wikis aims at the involvement of the students by letting them discuss their ideas and results of their tasks (Trowsdale & McKay, 2011). As a conclusion of research on project-based learning, Dym et al. (2005) suggest the involvement of different disciplines and cultures in (e-) learning environments to improve the learning effect.

As a further modern media for education, web-based portals can be named. Some of the already described web-based method portals and applications (see Section 2.1.3.2) serve mainly the teaching purpose like CiDaD (Lehrstuhl für Produktentwicklung, TU München, 2008) or pinngate (Jänsch et al., 2006). Other platforms assist the self-learning phase via plugins in different ways like studIP (StudIP, 2018) or moodle (Dougiamas, 1999). Further possibilities are mobile applications that provide small games or other gamification strategies. The purpose of these games is the enhancement of motivation due to a playful environment (Blohm & Leimeister, 2013).

Special formats using mostly online material like videos are flipped or inverted classroom concepts, e.g. Muñoz-Merino et al. (2017), Tolks et al. (2016), Massive Open Online Courses (MOOC), e.g. Lebrun et al. (2015), or the reduced variant as a Small Private Online Courses (SPOC), e.g. Kloos et al. (2015). The concept of an inverted classroom is that the self-directed learning phase and the face-to-face phase are flipped. In the form of online material, which can be accessed by the learners, the knowledge is transferred in a self-directed learning phase. Each learner can select from a variety of material and choose those media most attractive to them. The face-to-face phase is subsequently used to discuss and provide feedback (Kloos et al., 2015; Tolks et al., 2016). Tolks et al. (2016) compare this inverted classroom concept to traditional lectures using the taxonomy of Bloom et al. (1956), see Figure 2-24. The higher classes of educational objectives can be addressed in the limited face-to-face phases whereas the basics shall be learned individually.

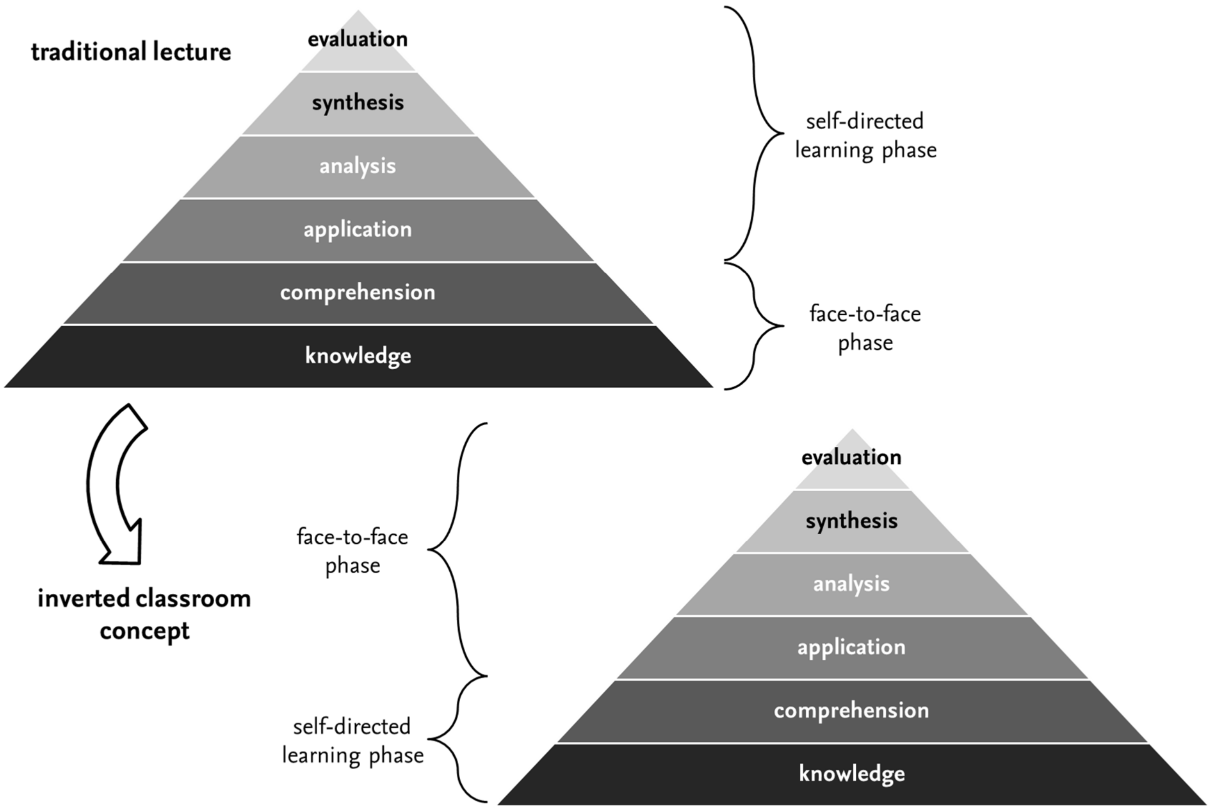


Figure 2-24 The traditional lecture and the inverted classroom concept in schematic comparison using Bloom's taxonomy according to Tolks et al. (2016)

MOOCs and SPOCs, in contrast, provide in general only online material. There are no face-to-face phases conceived. An example for a MOOC in the context of product development entitled "Product Design" is provided by the TU Delft (van Boeijen & Daalhuizen, 2018). As the absence of a supervisor or teacher is challenging for many participants in online courses, blended formats meaning online courses combined with face-to-face phases, e.g. at the beginning and at the end of a course, can overcome this problem (Rovai & Jordan, 2004). The main challenge of a decreasing motivation and resulting high dropout rates of online courses can also be faced by blended formats. One of the major advantages of online courses and in general online material is the time independence. The material can be accessed any time and as often as needed. In contrast, high expenses for the production of videos and other material like mobile applications or games have to be considered.

2.3.3 Method knowledge transfer and training

This section deals with the special training and transfer of method knowledge in an engineering design context. Weiß and Birkhofer (2006) differentiate between practice (workshops) and education (teaching and learning). They use the pinngate approach to address both target groups (see also chapter 5). Furthermore, Lenhart and Birkhofer (2006) stress the importance of considering the level of expertise and experience when training design methods or other methodical knowledge. They use a scale from novice to expert and classify the learners in learning, teaching and application context (Lenhart & Birkhofer, 2006).

According to Beckmann et al. (2014), there are five types and contributions to method knowledge transfer. They divide these types and contributions in short-term and long-term knowledge transfer. Implementation of methods and continuing education, e.g. training workshops in practice, belong to the short-term transfer types. Cooperation of research and practice, university education and consolidating design research are assigned to the long-term transfer (Beckmann et al., 2014).

The following sections will focus on the method knowledge transfer in design education (university context) and on the transfer to practice corresponding to the differentiation of Weiß and Birkhofer (2006). The last section will give an overview of existing success factors and barriers for method knowledge transfer in general (education and practice).

2.3.3.1 Design education within studies and formation

The research on design education can be stated to start in the 1960s. Before that time, engineering design was considered to be an art which is hardly teach- nor learnable (Andreasen et al., 2000). The working environment has changed a lot since then and so has the design education. Beside the professional knowledge like designing machine elements or sketching, soft skills and knowledge on processes are seen as important elements of current design edcuation (WiGeP, 2014).

However, at most of the technical universities in Germany, where engineering disciplines are taught, the phenomenon can be observed that mostly more than 100, sometimes even more than 500 students attend the basic courses. Additionally, the groups of learners are heterogeneous. As a consequence, many courses are held as ex-cathedra teaching with presentations of the professor, e.g. acatech (2012), Geis et al. (2010) or Bavendiek, Ring et al. (2017). The required soft skills and methodological competencies are mainly taught theoretically, which does not match the requirements of qualifications for future engineers and the guidelines of the WiGeP (2014). The application of design methods is rarely possible, except for special laboratory courses or projects. Some universities focus on project-based learning like the Karlsruhe Institute of Technology (KIT) has been doing since 1998 (Albers et al., 2000). There are further approaches like assisting portals (Krebber et al., 2011) or special training (Geis, 2011) using reflective tools (Geis & Birkhofer, 2009).

Jänsch (2007) introduces a checklist for method teaching. The checklist comprises the following elements: content, exercises, learning environment, trainer/teacher, tools, method descriptions, examples, structure and course of the lecture/class. She proposes different possibilities on how each element could be arranged, realised or implemented in engineering design courses dealing with methods. Furthermore, she suggested different pieces of training concepts and didactical methods with regard to required method knowledge transfer.

Table 2-7 illustrates the different types of method knowledge and corresponding so-called teaching methods as presented in Jänsch and Birkhofer (2007).

This section is meant to give only a short overview of the current state of design education as experienced at many German universities. A detailed analysis of existing approaches to train engineering design methods in design education will be presented in chapter 5.

Table 2-7 Mapping cognitive requirements on method knowledge transfer to suitable training concepts according to Jänsch and Birkhofer (2007)

cognitive requirements when learning design methods	suitable teaching methods
domain specific knowledge (e.g. mechanical engineering)	instruction, repetition, practicing, PQ4R, examples
multi-domain specific knowledge (e.g. mathematics, electronics)	instruction, repetition, practicing, mind-mapping, PQ4R, examples
meta-cognitive knowledge (e.g. difficulty of a task)	failure critic with feedback, imparting information about cognitive strategies, strategies for resource management and motivation
meta-cognitive skills (e.g. planning, controlling)	feedback, regulation checklists, self-asking techniques, thinking aloud, SOAR
cognitive skills and abilities of experts (e.g. abstraction)	repetition, practicing, imparting information about cognition, design methods

2.3.3.2 Method training in practice

The gap between design research and engineering practice with regard to the application of design methods is widely discussed, e.g. Geis, Bierhals et al. (2008), Jänsch (2007), Schneider et al. (2006), Wallace (2011). Thus, there are various approaches to transfer design methods from research to practice. Beckmann et al. (2016), for instance, give an overview of different transfer approaches. They name the Model for Strategic Planning of Method Integration (Viertlböck, 2000), the Munich Model of Methods (Braun & Lindemann, 2003), the Method Implementation (Stetter & Lindemann, 2005), the Method Transfer Model (Geis, Bierhals et al., 2008) and the Process for the Implementation of Idea Processes (Messerle et al., 2014). Based on these models and approaches, Beckmann et al. (2016) present their own transfer model focussing on methods for developing product families. The similarity of all of these approaches is the definition of different stages or pillars for the transfer. Most models have in common that first the user's needs have to be considered, second the methods have to be prepared and or selected, and third have to be adapted and finally are implemented in the company in question.

More general considerations propose the differentiation of individual training, workshops and pilot projects (Araujo, JR, 2001). A similar classification is suggested by Weiß and Birkhofer (2006) as cooperation projects and transfer workshop but they add seminars as ex-cathedra teaching of design methods in small groups of practitioners. They introduce the Project Guide as assisting web-based portal to plan and prepare transfer workshops.

As for the design education section, this section only provides a brief overview of different transfer concepts from research to practice. Chapter 5 will be used to analyse existing approaches in more detail.

Finally, the consideration of change processes and management is important when introducing new methods, tools or methodical procedures in existing structures of companies. The topic of change management will not be considered in detail. However, some aspects will be mentioned among the subsequently presented barriers and success factors.

2.3.3.3 Success factors and barriers of method transfer

Corresponding to literature dealing with transfer problems of design methods, success factors and barriers are often mentioned in this context. A success factor is a mean or aspect having a positive influence on the implementation of design methods in practice but sometimes also referred to design education. A barrier, in contrast, hinders the successful transfer or implementation of a design method into a company or education.

Various surveys in industry tried to identify success factors and barriers for method knowledge transfer and the frequency of method application in practice as well. An overview of existing surveys is given, e.g. by Schneider et al. (2006). More recent research conducted further surveys coming up with similar results (low method usage in industry), e.g. Bavendiek et al. (2014) or Albers et al. (2014). Beckmann et al. (2016) gathered success factors and barriers on method transfer from literature. Later, they interviewed industry partners to confirm the factors and barriers found.

Main success factors, sometimes formulated as requirements on method transfer or as commandments are the comprehension of the organisation’s needs, the adaption of methods, simple methods, pilot projects, management support as well as convincing and involving the persons concerned, e.g. Beckmann et al. (2016), Birkhofer et al. (2005), Jänsch et al. (2006), Lohmeyer et al. (2014).

More frequently, barriers or problems with design methods leading to a low acceptance and application of methods in practice are mentioned in literature. Araujo, JR (2001) and Andreasen (2003) name, for instance,

- too theoretical and abstract methods,
- difficult to implement and to use,
- poor information on the methods,
- no evaluation of the results attained with the method, and
- a lack of investigations into the fitness and usefulness of methods

as main barriers based on survey results from companies in the United Kingdom (UK) and Denmark. Jänsch (2007) as well as Geis, Bierhals et al. (2008) additionally mention a distance to daily work, low flexibility and high effort to adapt methods as problems of methods in practice. Schmidt-Kretschmer and Budych (2009) investigate the usability of methods referring to the ISO standard 9241 "Ergonomics of human-system interaction - Part 110: Dialogue principles" (ISO 9241-110:2006). They identify requirements on the provision but also on the training of methods in general.

2.4 Summary of the state of the art

This chapter assigned the underlying research work to the field of systematic engineering design within the development of products. After a short introduction to different general and problem-solving procedures within the design process, the focus was set on engineering design methods as well as their application and provision in practice. Among the provision of methods, it was differed between method description, collections, selection or access, and adaptions.

The following sections addressed the design organisation focussing on the design team and its characteristics. Ways to assess these characteristics were additionally highlighted. Due to an increasing digitalisation and a thereby resulting increasing virtual work, potentials and challenges as well as characteristics of virtual teams were presented and compared to traditional teams. The term of the degree of virtuality was introduced in this context.

The last part of this chapter dealt with general didactical concepts like learning and educational theories, types of learners as well as media and formats for education and training in practice. A special focus was put on the training and transfer of design methods in education and in practice. Success factors and barriers for training and transfer were mentioned. The next chapter will use these findings to clarify the problem that is addressed in this thesis. Based on this, the research gap is identified.

3 Problem Clarification

"People are in such a hurry to launch their product or business that they seldom look at marketing from a bird's eye view and they don't create a systematic plan."

Dave Ramsey, American businessman and radio moderator

Based on the findings of the state of the art (chapter 2) and having the research approach and research questions (chapter 1) in mind, this chapter aims at the clarification and refinement of the problem in terms of the research gap to be addressed. This will be done in the first part of this chapter (Section 3.1) by summarizing the findings of previous research. Subsequently, the second part of the chapter (Section 3.2) deduces intended results of this thesis based on the research gap. It clarifies the research goals of chapter 1 and assigns the research questions to the intended results, which will be achieved by answering the questions.

3.1 Refinement of the research gap

As already introduced, the findings of the state of the art will be summarized in the following. For a better overview the main aspects are organised in Figure 3-1. Each of the mentioned aspects will be referred to subsequently.

In engineering design practice (right side of Figure 3-1) there is often such a tight schedule in the development process of products that a systematic approach is missing. So generally, it is worth stepping back and deciding on a systematic approach upon the design task. Big companies but only few small and medium-sized enterprises provide a guideline or systematic approach for their engineers on how to develop a new product (Vietor, 2015). However, the findings indicate a low usage of methods in industrial practice, e.g. Badke-Schaub et al. (2011), Geis, Bierhals et al. (2008), Jänsch (2007), Reinicke (2004), Wallace (2011).

Jänsch (2007) and Reinicke (2004) refer to the high degree of complexity and theoretical overload of method descriptions as a barrier to the application of methods. The low personal and time capacity is also mentioned as a barrier to the acceptance and application of methods (Geis, Bierhals et al., 2008). Surveys conducted in different countries could mainly confirm these statements, e.g. Araujo, JR (2001), Schneider et al. (2006). Additionally, to the mentioned barriers, a wrong team composition and negative feedback from involved employees in the methods were named (Schneider et al., 2006).

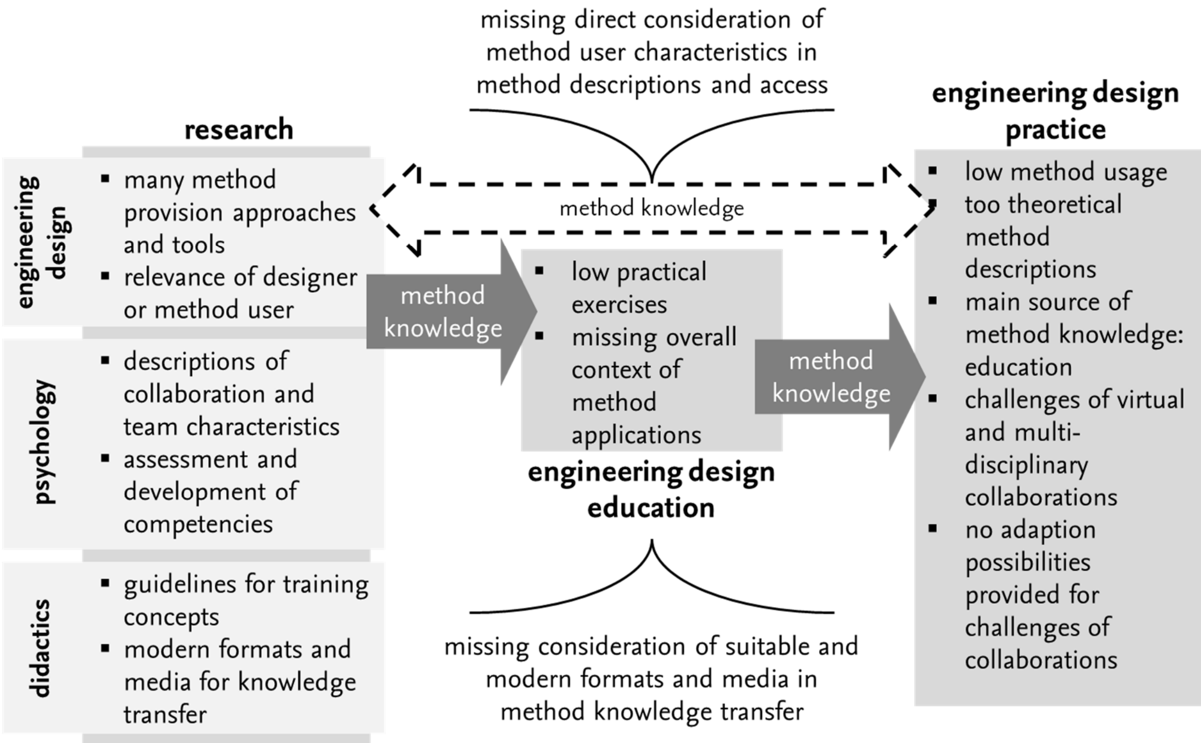


Figure 3-1 Identification of the research gap summarizing findings from the state of the art

Regarding the barrier of missing adaption possibilities for methods, Badke-Schaub et al. (2011) specify theses missing adaptation possibilities as adaptions to the method user and the design situation. Thus, the consideration of the method user and the team applying the method should become an important aspect when providing methods. Also considering the increasing digitalisation of the working environment and the simultaneous increasing work in multidisciplinary or virtual teams, the conditions for a method application can be diverse depending on the team or method user. The conditions might even be so varied that some methods cannot be applied. An example is the Brainwriting method, which is hardly applicable without adaptions in a locally distributed team due to the physical interactions (exchange of ideas on paper) between the method users. So, on the engineering design practice side, there is a need for adaption possibilities of methods to the new challenges of the daily work.

Coming to research (left side in Figure 3-1), there exist already lots of approaches to support the design process with methods, tools and in a systematic way, e.g. Cross (2007), Feldhusen and Grote (2013), Lindemann (2009). The application of methods promises benefits as presented in chapter 2. Even the examination of more than 400 development projects within a study could confirm positive effects of the application of methods regarding the success of the final product as well as the time spent on the development of the product (Graner, 2013).

Additionally, the relevance of the design situation and also of the designer as method user is claimed by several authors, e.g. Badke-Schaub et al. (2011), Braun (2005), Ponn (2007). Research from the area of psychology and research on collaborations provide already team and collaboration characteristics that can be used to describe the method user characteristics, e.g. Anderl et al. (1999), Kauffeld (2006b), Nerdinger et al. (2014). Even the assessment of these characteristics and of competencies is widely available, e.g. Kauffeld (2001). Though, there is a research gap since the consideration of the method user characteristics directly in method descriptions and in the access to methods is lacking.

Finally in engineering design education (centre of Figure 3-1), the amount of practical exercises is mainly low. The great number of students allow often only presentations and lectures with a low practical application of methods (acatech, 2012). In addition, there is a course-based view on the content, which hinders an overall view on systematic approaches and the connection to methods (Bavendiek et al., 2016b).

Didactics on the research side provides guidelines and basics for the design of training and modern formats and media. Especially guidelines for training (Geis, Birkhofer et al., 2008) and advice for the preparation of teaching material (Jänsch, 2007; Lenhart & Birkhofer, 2007) were taken up and transferred to engineering design education. The idea of providing method descriptions to students in a database is also not new, e.g. Jänsch et al. (2006), Lehrstuhl für Produktentwicklung, TU München (2008). However, modern formats like MOOCs and media like videos are rarely found for method knowledge transfer in design education. Since education is the major source of method knowledge in practice, the strengthing of the method education is seen as a promising approach to enhance the method acceptance in practice in the long-term.

3.2 Intended results

To address the identified research gaps, the aim of this thesis is the development of a team-oriented method provision that takes the team or the method user under consideration when describing and accessing design methods. The three main intended results of this thesis and their connections to each other are presented in Figure 3-2 in white boxes numbered from (1) to (3). Based on the ARC diagram of chapter 2, the areas of contribution are framed in black whereas the central topic of this thesis is located in the centre of Figure 3-2. This central topic is the design method knowledge transfer to which the thesis shall contribute the highlighted aspects to make this transfer more successful.

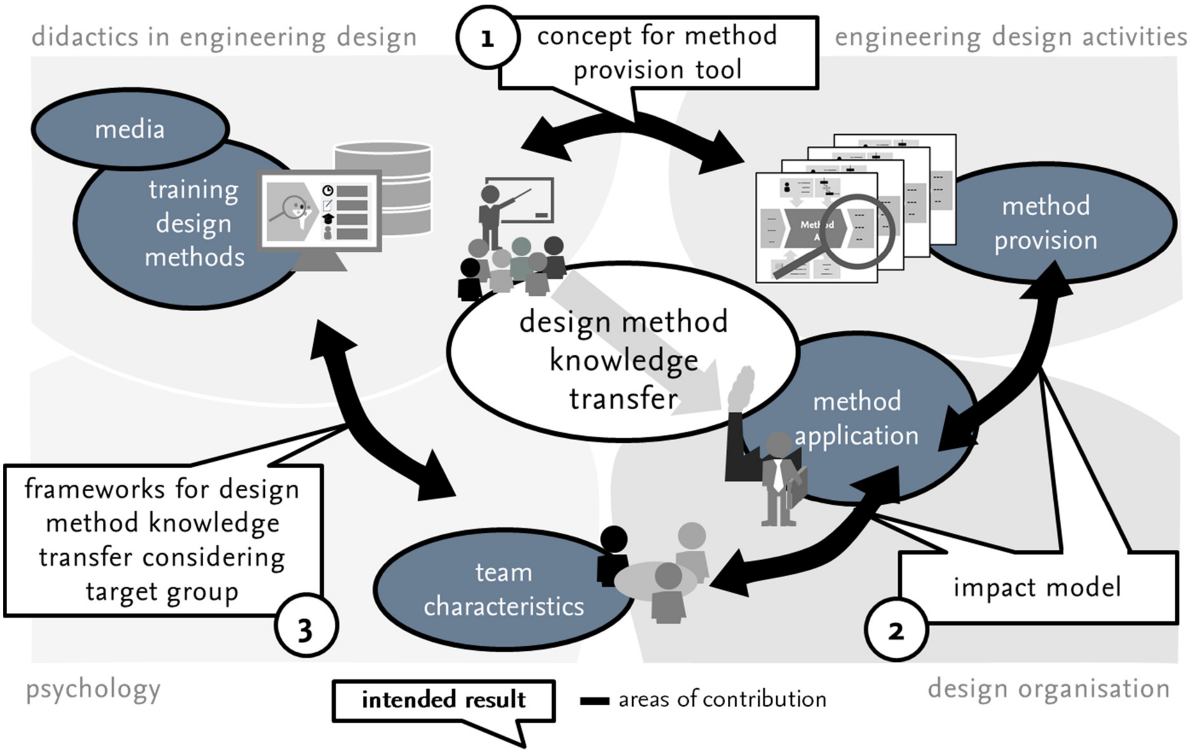


Figure 3-2 Vision on the results of the thesis and their connections to each other

As a first step towards the aim of a team-oriented method provision, research question Q1 *"How are engineering design methods provided in existing method descriptions and collections?"* shall be answered by analysing existing method provision approaches regarding team aspects and other attributes (chapter 4). The results help to answer research question

Q2 *"What are requirements on a suitable method provision in engineering design?"* So, requirements for a team-oriented method provision tool will be derived. These will be the basis for the first intended result, the concept of a method provision tool (see no. (1) in Figure 3-2).

To include a consideration of the team and the method user, general method user characteristics will then be analysed regarding their influence on the method application. This will lead to an answer to research question Q3 *"How do method user characteristics influence the methods' application in engineering design?"* The results are used to build a corresponding impact model in chapter 6 (see no. (2) in Figure 3-2). Subsequently, the results serve as a basis for the answer to research question Q4 *"How can method user characteristics be identified and considered in method provision and application?"* The impact model provides the relevant information to add method user characteristics to the concept of a team-oriented method provision tool (result no. (1)).

Finally, the third intended result of this thesis refers to the training and transfer of the above-provided method knowledge. Based on the finding that education is the main source of method knowledge (Bavendiek et al., 2014), the assumption was stated that a better, long-term oriented training of method knowledge will lead to a more profound method knowledge for the future engineering practitioners. Nevertheless, a long-term oriented method training is also favourable for current practitioners, e.g. in the context of workshops. Adding the aspect of modern formats and media to method knowledge transfer, the third intended result is the development of a framework for a long-term oriented method knowledge training and transfer to practice, see no. (3) in Figure 3-2. The consideration of method user characteristics plays again a role. To achieve this result, research question Q5 *"What are success factors and barriers for method knowledge transfer in design education and practice?"* is answered in chapter 5, which presents the analysis of suitable method knowledge transfer approaches. The analysis leads to requirements for a framework of method knowledge transfer for the target group design education and for practice. The development of these frameworks will be described in chapter 7. They give an answer to research question Q6 *"What are successful means for method knowledge transfer considering the target group?"*

The three intended results of the thesis combine to a team-oriented provision and training of engineering design methods for design education and practice. In chapter 8 the benefits of this work are shown by realising several studies while also discussing possible improvements to this approach.

4 ANALYSIS OF METHOD PROVISION APPROACHES

"At all times it is better to have a method."
Mark Caine, American writer

Having a method in the context of engineering design processes can be a suitable approach to deal with the overall design task. Even each step of the design process can be supported by a method. However, there exist so many design methods that knowing them all seems almost impossible. This is why different authors (see Feldhusen and Grote (2013), Lindemann (2009)) started to collect and describe methods with the goal to simplify the use of them for engineering designers. Some authors added special facilities to better and systematically access the methods. This chapter analyses various method collections and their access possibilities to answer research question Q1: *"How are engineering design methods provided in existing method descriptions and collections?"* The answer helps to identify generally relevant elements of method descriptions that facilitate the application of the method described. In addition, current team-oriented aspects in method provision approaches will be outlined. These team-oriented aspects will be used to generate a concept for a team-oriented method provision tool in chapter 6.

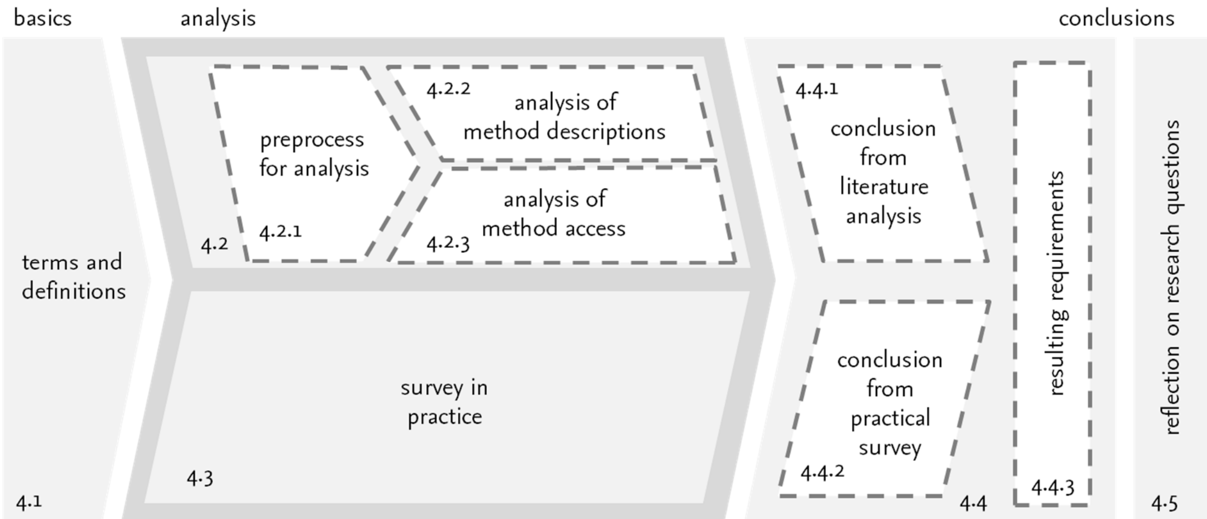


Figure 4-1 Schematic illustration of the chapter's structure

Figure 4-1 outlines this chapter's structure. As a basis Section 4.1 will start with terms and definitions needed for the following analysis sections.The analysis is divided into the literature-based analysis of the method descriptions and method access in Section 4.2 and the analysis of demands for method provision that is based on survey results from practice in Section 4.3. To start the literature-based analysis, preprocessing is required (cf. Section 4.2.1) for the analysis of method descriptions (cf. Section 4.2.2) and the analysis of method access (cf. Section 4.2.3). The second part of the analysis, a survey in engineering design practice, is described in Section 4.3. Section 4.4 concludes the analysis results to gather requirements on a team-oriented method provision and to address research question Q2: *"What are requirements on a suitable method provision in engineering design?"* To do so, both parts of the analysis will be summarized to deduce the requirements for a team-oriented method provision concept. The chapter ends with a reflection on the research questions (Section 4.5).

4.1 Terms and definitions

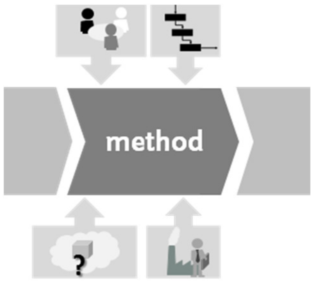
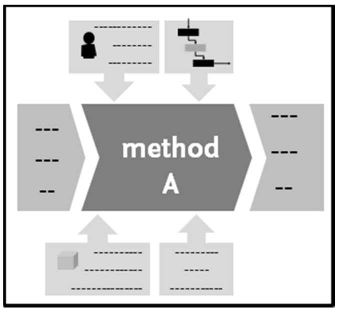
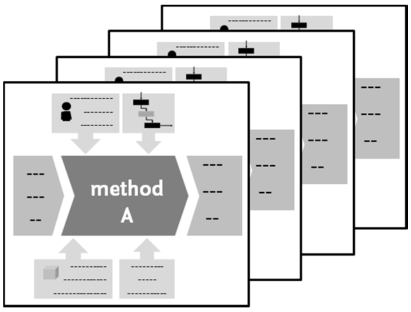
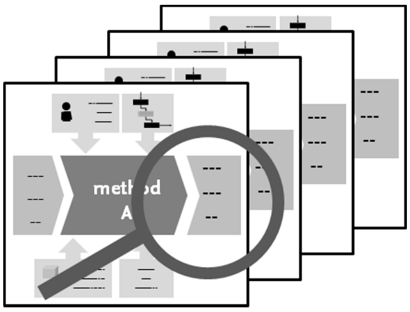
For a better understanding of the following sections important and recurring terms will be defined first.

Definition of important terms

The term "method" was already defined in chapter 2 as follows: "*A method provides an operatively applicable thinking and behaviour pattern to achieve a goal."* (Vietor & Lachmayer, 2016)

In the following, several terms with no or only little definition in literature will be presented. These terms are *method description model*, *method description*, *method collection*, *method access (possibilities)* and *method provision*. Table 4-1 gives an overview of the terms mentioned and their definitions while they can also be found in the glossary of this thesis. Next to each term a pictogram can be found, which will be used in the following figures. Each term will be explained in detail in the following.

Table 4-1 Overview of important terms, corresponding pictograms and definitions

Method Description Model		Method description models define in an abstract way how to describe a method in a structured manner by uniform attributes.
Method Description		A method description contains information about a (design) method. In this thesis, only structured and uniform descriptions that describe each method with the same attributes are considered as method descriptions.
Method Collection		A method collection consists at least of more than one method description. It serves the purpose to provide method knowledge to the user of the collection. It can be paper- or web-based.
Method Access (Possibilities)		The method access determines the way to search, select and access methods. There are different possibilities like matrices of criteria or filter options.
Method Provision		Combining method descriptions with an access to the content is the provision of methods.

The term method model is widely used in various fields of research for diverse meanings and types of methods, models and tools. Birkhofer, Kloberdanz, Berger et al. (2002) also introduce the term as Process-oriented Method Model (PoMM). To distinguish between *method access* and *method description*, in this thesis, the term method model is specified more precisely using the three different terms *method description*, *method access* and ***method description model***. The terms *method description* and *method access* stand for existing descriptions and accesses to methods. The extension *model* for *method description* signifies that it is a model of how to describe a method. Similarly, there could be a method access model.

Reviewing literature from different fields, the term ***method description*** is widely used in the scientific world to describe the research method. The important difference to these meanings is the formalized manner, which is a criterion for the *method descriptions* considered in this thesis (see Section 4.2.1.1).

The term ***method collection*** is not very common in English. In other disciplines the expression *collection of methods* are used but it is rarely found for engineering design methods, e.g. Strasser & Grösel (2004) or Franke & Deimel (2004). In German the term is known as “Methodensammlung”, several authors like Albers et al. (2015), Strasser (2004), Reinicke (2004) or Ponn (2007) use it more commonly. In this thesis, the term *method collection* is used because of the similar word structure compared to the other terms like *method description*.

The term ***method access*** is built similarly to the term *method description*. For instance, it is found in literature of Birkhofer. Birkhofer et al. (2002) mention “requirements for the contents, description and access of design methods” and name some elements of the PoMM “access modules”. Some authors write about the method selection, e.g. Albers et al. (2014), Nieberding (2010) or López-Mesa (2003), in the context of method application. This is only one facet of the term *method access*, which includes not only the process of selecting a method from a content viewpoint but also the different types of access like lists or search options.

Finally, a composition of *method descriptions*, which is a *method collection,* combined with a *method access* is called ***method provision*** in this thesis. The term is based on the expression information provision. The expression “provide methods” is commonly used in

German as "Methoden bereitstellen", e.g. Ponn (2007), and by German-speaking authors like Sauer et al. (2003) or Guertler (2016) in English as well. Thus, the term *method provision* is defined for the thesis as *"combining method descriptions with an access to the content"*.

Summing up, Figure 4-2 illustrates the relations between the introduced terms *method description model*, *method description*, *method collection*, *method access* and *method provision*. In the following, these terms will not be italicised anymore.

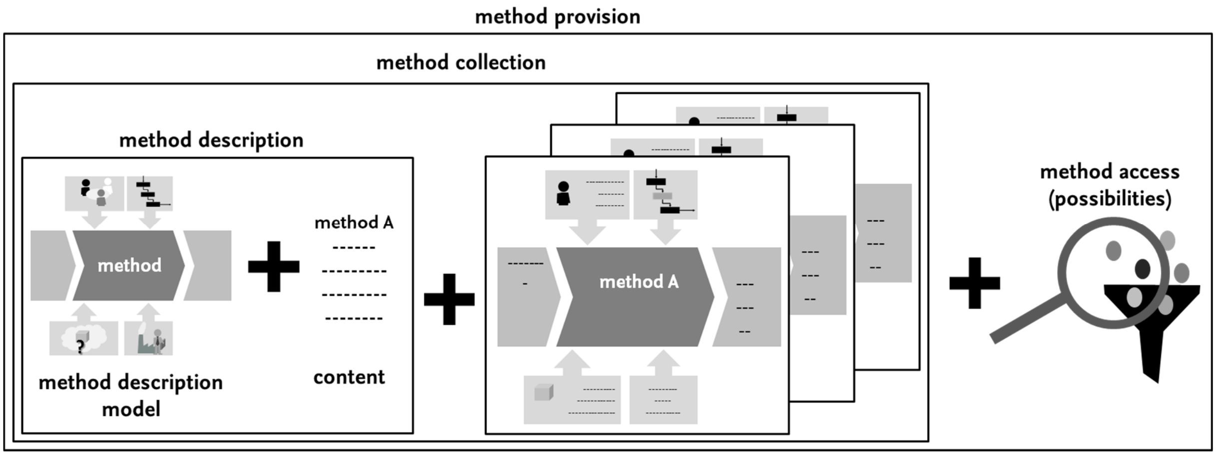


Figure 4-2 Relations between the introduced terms

Attributes for method descriptions

Method descriptions contain describing attributes. An attribute is a single element to describe a certain characteristic or characteristics of a method. Examples for attributes are the *description of a method* or the *team size* best fitting to apply a method. Some of the attributes are described according to the method in text format or bullet points. For other attributes, it seems reasonable to define predetermined characteristics or values like for the *team size* possible values are »1«, »2-3«, »4-6«, »7 and more« team members. In the following, these characteristics or values will be referred to as values to distinguish better from method user characteristics.

Attributes to describe methods can be derived from various fields. Most obvious are attributes directly describing the method like the method name, a short description, illustrations or the procedure to apply the method. Additionally, attributes providing information about the situation and certain boundary conditions like the task or the users of the method can be identified in existing method descriptions. For example, Ponn (2007) distinguishes between information on:

1. the design task and the product,
2. the designer and the team, and
3. further boundary conditions.

These distinguishing groups will be referred to as clusters in the following. Thus, a cluster consists of multiple merged attributes that belong to a similar group. Due to the focus of this thesis on the design team, the proposed clusters of Ponn (2007) will be adapted. The second cluster of Ponn, the designer and the team, is adopted and called *team / user specific* referring to the method user. Furthermore, *method specific* attributes as explained above are merged in another cluster. These attributes can be seen almost independently of the task, the situation or other circumstances. Ponn's cluster design task and product is transferred into the cluster *task / situation specific*. Choosing the term *situation* for this cluster allows avoiding a wide cluster like further boundary conditions. Attributes, which do not fit into the above-mentioned clusters but provide additional content like templates or links to method experts, are summarized in the cluster *additional content and tools*. The four resulting clusters are shown in Figure 4-3. In this figure, next to the clusters the relation between cluster, attribute and value is demonstrated with an example.

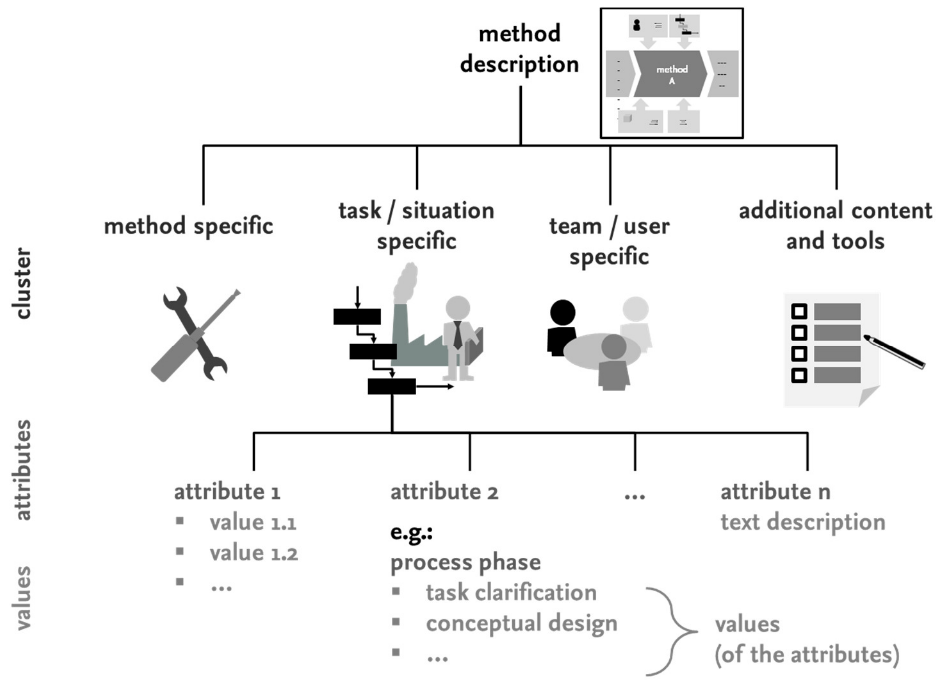


Figure 4-3 Relation between clusters of method descriptions, attributes and values

The attributes belonging to the clusters will be deduced in Section 4.2.1.2 in detail. The clusters defined here were established after determining the final attributes. For a better understanding the clusters were presented beforehand.

4.2 Literature-based analysis of method provision approaches

The first part of this section describes the preprocessing which consists of several steps like selecting the method collections to be analysed and defining criteria for the analysis. The second part of this section analyses the method descriptions regarding team aspects and other describing attributes. The third part is the analysis of method access while considering amonst others team aspects. Conclusions regarding the team-oriented method provision tool in terms of deduced requirements are given in Section 4.4.1.

4.2.1 Preprocessing of analysing method provision approaches

To analyse existing method collections and models regarding their describing attributes and access possibilities, a preprocessing is necessary. First of all, suitable collections and models have to be identified, then the attributes are derived from these method collections and models to build and formulate a set of attributes for each cluster. Subsequently, different method access possibilities are gathered from the chosen collections and models to enable a systematic analysis of the access possibilities. The final prepocessing step is the definition of formalities to evaluate the method collections and models regarding uniform criteria. The criteria are differentiated into criteria for method descriptions and method access.

4.2.1.1 Selection of method collections and models

With the aim to develop a method provision tool that focuses on the user and the team that applies the method, more than 30 existing method collections and models were found between March 2014 and July 2017. Not all of them seem to be appropriate for the final analysis due to different reasons. Some provide no structured and uniform format; others are not or no longer available and could only be found in literature.

In general, two different types of method collections can be defined:

1. paper-based versions like print media or online available documents, and
2. web-based versions like method portals or mobile applications.

Independent of the type, criteria for selecting the method collections and models to be analysed are defined as follows:

- topic: description of at least one engineering design method that is typical for this discipline,
- structure: structured descriptions with the same attributes for all methods,
- language: language of the method collection or model is German or English.

The first criterion is meant to narrow the found collections down to the relevant ones. The collections shall contain engineering design methods like creativity methods, project management methods, evaluation methods, etc. An exception for this criterion are method description models, which mainly provide only one exemplary description of a method. In this case it is important that the model originates engineering design disciplines like the Process-oriented Method Model of Birkhofer, Kloberdanz, Berger et al. (2002).

The second criterion includes only collections that describe all contained methods with the same attributes. Hence, a structure has to be identifiable. This criterion is estimated as very important because several authors claim that descriptions varying in content and structure hinder the application of methods in practice, e.g. Birkhofer, Kloberdanz, Berger et al. (2002) and Geis, Birkhofer et al. (2008). The representation of methods influences among other things the acceptance of methods.

The third criterion restricts the method collections to German and English results. There are mainly two reasons for the use of this criterion: Firstly, the research field on providing design methods is dominated by German research projects, which were not always published in English in the past. Secondly, English is the international trade and communication language.

Examples are used in Figure 4-4 to demonstrate the selection process. On the left hand, of the figure the criteria are shown. The first column shows examples and reasons for refusing these method collections. On the right hand, two examples of selected collections are presented. The third criterion regarding the language is not demonstrated.

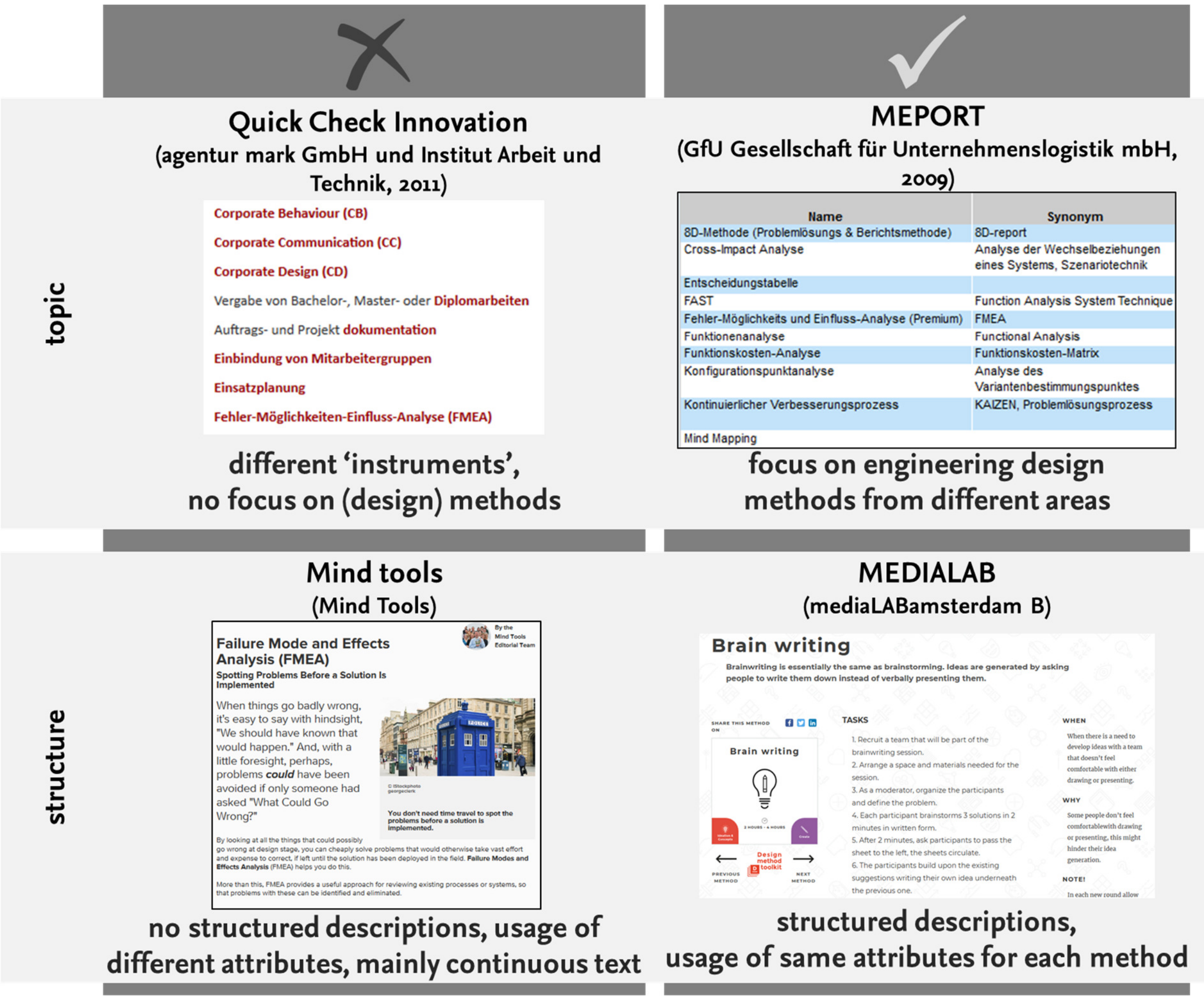


Figure 4-4 Examples of the selection of method collections and models for the analysis

In the following the search results of method collections and models are presented. Table 4-2 shows the paper-based versions. Besides the name and the author of the collections and models, the publishing date, if known, the domain in focus of the method descriptions as well as the number of methods contained in a collection are indicated. Remarks give information on the source and availability of the collections and models. The second to last column indicates if the collection or model is selected for later analysis. If it is selected, the last column shows the name for the collection or model used during the analysis and the further course of this thesis.

Table 4-2 Overview of the paper-based method collections and method description models

paper-based method description models / method collections							
name	author/editor (as indicated in references)	year	main domain and topics	no. of methods	remarks	selection for analysis	abbreviation (as used in text)
Methodische Entwicklung technischer Produkte	Lindemann, 2009	2009	product development	82	appendix of book	!	(analysed as CIDAD in web-based)
PoMM - Process-oriented Method Model	Birkhofer, Kloberdanz, Berger et al., 2002	2002	product development	0	the analysis is based on the theoretical description of the model	!	BIRKHOFER
Design methods for developing services	Design Council	?	Design Thinking	11	online available	✓	DESIGN COUNCIL
Aufgabenorientierte Methodenanpassung in der Produktentwicklung am Beispiel Qualitätsmanagement	Dobberkau, 2002	2002	quality methods	17	appendix of PhD-Thesis	✓	DOBBERKAU
Innovationsmanagement	Eversheim, 2003	2002/3	innovation	38	appendix of book	✓	EVERSHEIM
IPH-Methodensammlung	IPH – Institut für Integrierte Produktion Hannover gemeinnützige GmbH, 2009	2009	product development, production	73	online available	✓	IPH
Methodenhandbuch Nutzerzentrierte Entwicklung	Kompetenzzentrum Usability für den Mittelstand, 2015	2015	software development	24	online available	✓	KUM
Designmethoden - 100 Recherchemethoden und Analysetechniken für erfolgreiche Gestaltung	Martin & Hanington, 2013	2013	Design Thinking	100	complete book	✓	MARTIN
Situative Unterstützung der methodischen Konzeptentwicklung technischer Produkte	Ponn, 2007	2007	product development	36	appendix of PhD-Thesis	✓	PONN
SPP Projekt	Gausemeier et al., 2004 respectively Braun, 2005	2004/5	innovation	1 (in database 60)	the analysis is based on the theoretical description of the model as the orginal database was not accessable	!	SPP
Landscape of Methods	Strasser, 2004	2004	product development	74	appendix of PhD-Thesis	✓	STRASSER
Method Cards	IDEO, 2003	2003	Design Thinking	51	heterogeneous descriptions on the cards, always pictures (front) and text (back)	✗	

explanation:
- ✓ selected for the analysis
- ! selected for the analysis with restrictions or as part of another collection
- ✗ not selected for the analysis

Table 4-3 Overview of the web-based method collections and method description models

web-based method description models / method collections and mobile applications							
name	author/editor (as indicated in references)	year	main domain and topics	no. of methods	remarks	selection for analysis	abbreviation (as used in text)
18F Method Cards	18F	?	Design Thinking	31		✔	18F
27 creativity & innovation techniques explained	Vullings & Heleven, 2013	2013	creativity methods, innovation	27	onepager	✔	27C&I
CiDaD	Lehrstuhl für Produktentwicklung, TU München, 2008	2008	product development	82	no free access	✔	CIDAD
The circular design guide	MacArthur, 2016	2016	Design Thinking	24		✔	CIRCULAR
DesignKit	IDEO	?	Design Thinking	61		✔	DESIGNKIT
designmethodenfinder	Söffing, T., Ottmann, M., Nagel W. Fischer, V., 2010	2010	Design Thinking	ca. 60	no longer available (since may 2017)	!	DMF
dms Service Design	Stapelkamp, T., 2012	2012/13	service design	8	videos and short texts	✔	DMS
GINA Methodos	Institut für Konstruktionstechnik, TU Braunschweig, 2003	2003	product development	64	no longer available (since 2016)	!	GINA
InnoFox	Institut für Produktentwicklung, Karlsruher Institut für Technologie, 2014	2014	product development	91	mobile application, no free access	✔	INNOFOX
innovations-wissen.de	SPP GmbH, 2004	2004	innovation	50	content produced in SPP project (see paper-based models)	✔	INNOWISSEN
MAP-Tool	RPK - Thomas Paral, Karlsruhe, 2000	2000	product development	144	single descriptions vary strongly in quality and length	✔	MAP-TOOL
Design Method Toolkit for agile, team-based projects	mediaLABamsterdam B	?	Design Thinking	57		✔	MEDIALAB
Meport - Das Methodenportal	GfU Gesellschaft für Unternehmenslogistik mbH, 2009	2009	problem solving	58	free registration needed	✔	MEPORT
Projekt Magazin	Berleb Media GmbH, 2015	2015	project management	53	parts only with access available	✔	PM
WiPro	TIM, 2013	2013	innovation	115		✔	WIPRO
Quick Check Innovation	agentur mark GmbH und Institut Arbeit und Technik, 2011	2011	innovation	51	download as .docx format, mainly instruments instead of methods like accessment centre or corporate design for SME	✘	
Atelier für Ideen - Kreativitätstechniken	Atelier für Ideen AG	?	creativity methods	37	short descriptions with uniform attributs but heterogeneous texts	✘	
Mindtools	Mind Tools	?	divers topics: leadership, project management, decissing making, problem solving, ...	1167	heterogeneous descriptions with pictures and texts	✘	
Business method toolkit for agile, team-based projects	mediaLABamsterdam A	?	business methods	30	descriptions like design methods of medialabamsterdam	!	
servicedesigntools	Tassi, 2009	2009	Design Thinking	36	using case studies for description, heterogeneous descriptions	✘	

explanation:
✔ selected for the analysis
! selected for the analysis with restrictions or as part of another collection
✘ not selected for the analysis

The table contains 12 collections and models from which 11 are selected for the analysis. Three models or collections are chosen under certain restrictions: The collection provided by Lindemann (2009) equates to the content of the web-based version called CiDaD (Lehrstuhl für Produktentwicklung, TU München, 2008) whereas the web-based version provides broader access possibilities, therefore it is selected instead of the paper-based version. The models presented by Birkhofer, Kloberdanz, Berger et al. (2002) and Gausemeier et al. (2004) or Braun (2005) are description models. Gausemeier et al. (2004) or Braun (2005) show the description of one exemplary method from which not all necessary information can be derived. Birkhofer, Kloberdanz, Berger et al. (2002) describe the model in detail but there can be no final certainty about the contents of each attribute due to missing examples. This is why, at certain points no evaluation is performed, which will be remarked then.

Table 4-3 is structured similarly to Table 4-2. It lists the web-based versions of method collections and models. The table contains 20 collections. Based on the selection criteria four of them are not suitable for the final analysis. The MEDIALABAMSTERDAM collection of business models (mediaLABamsterdam A) equates in structure to the MEDIALAB collection of design thinking methods (mediaLABamsterdam B). Therefore, only the latter is considered. Two other formerly accessible online portals are inaccessible in July of 2017. These portals have been included in the analysis even though they might not be usable in the future. Refer to the corresponding internet links through the references.

In total, 25 method description models and collections as paper-based and web-based version will be analysed regarding their attributes and access possibilities.

4.2.1.2 Norming attributes for method provision

Norming the attributes for method provision means formulating uniform attributes which are used during the analysis and for the concept of the method provision tool in chapter 6. To build and formulate these final attributes the method collections and method description models identified in Section 4.2.1.1 are scanned. The procedure for identifying the final attributes takes place in four steps: scan, regroup, define and assign (see Figure 4-5).

Figure 4-5 Procedure to identify the final attributes for the analysis

The first step includes reviewing the existing method collections and models and filter out all possible attributes on how they are described in the models and collections. Then, the second step regroups similar attributes to one attribute to reduce the amount of different attributes. Subsequently, the third step defines the final attributes. In this step the final attributes are listed and explained in detail. This is important for the deeper understanding of the analysis. Finally, the fourth step serves the purpose to assign all elements of existing method collections and models to the final attributes. Each of these steps will be described in detail in the following.

1. Step: Scan

After the identification of suitable method collections and method description models, they are systematically scanned to filter out all describing attributes of each collection or model. The general procedure to identify the attributes is presented in Figure 4-6.

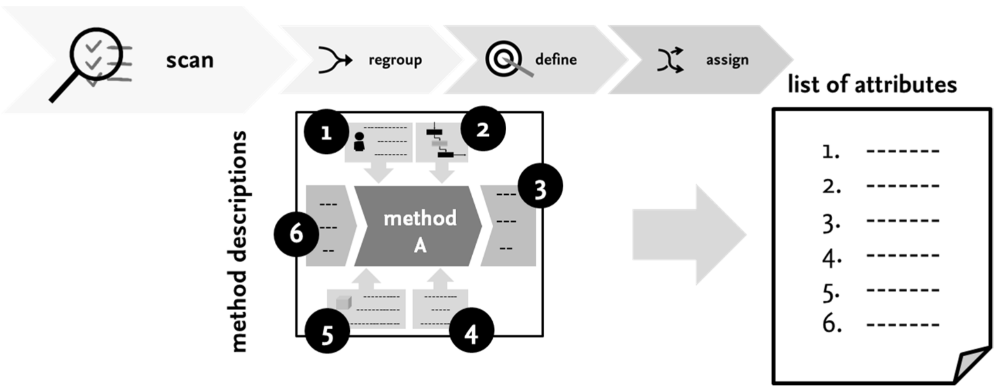


Figure 4-6 Step 1 of the identification of final attributes: scan

As an example the procedure is demonstrated with the aid of the method collection MEDIALAB (mediaLABamsterdam B) showing the method Brainwriting (see Figure 4-7). Each element is considered regarding its content. The elements are named as they are in the collections. In the example of Figure 4-7 certain attributes (6 to 10) are named by a title for some attributes. Therefore, the attribute name is easy to identify. Other elements of the method description are not named like the method name (1) or the short description (2). In addition, this method description provides a pictogram presenting the main idea of the method (3). The information in the corners below the pictogram are considered as classification possibilities (4) as every description of this collection sticks to the same classes in these fields. Furthermore, the time required (5) to apply the method is indicated directly below the pictogram. These elements, which are not directly named by a title in the collections, are summarized with the same name of an attribute for each collection or model, for instance *required time effort* for all types of time specifications. The procedure is applied to all above-mentioned method collections and models. In total, more than 120 differently named attributes are found and listed.

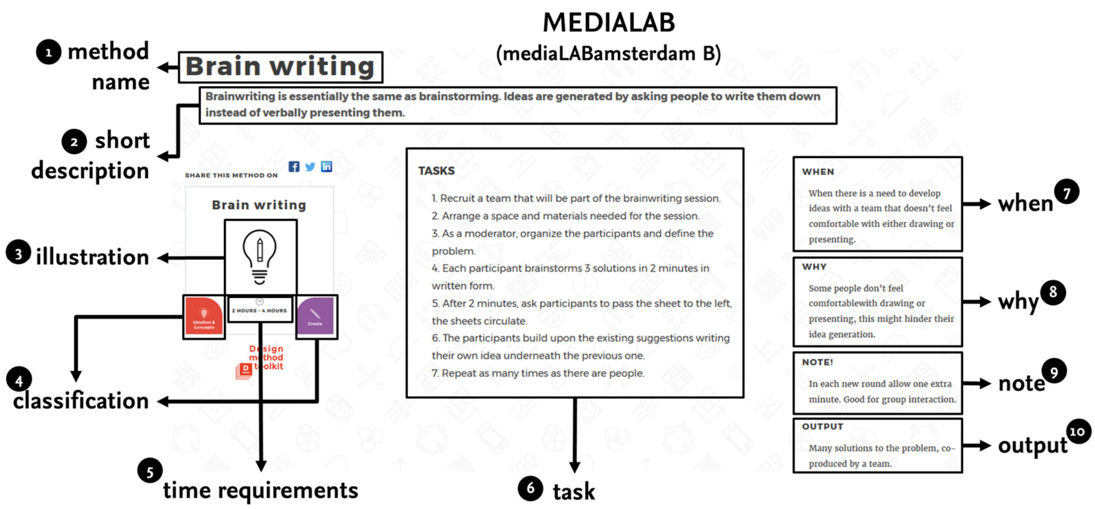


Figure 4-7 Example of the scanning step to identify attributes from the collection mediaLABamsterdam B

2. Step: Regroup

Due to the high amount of different attributes the next step aims at the reduction of this number and at the regrouping of similar attributes. The general procedure is presented in Figure 4-8 and an example will be described in the following.

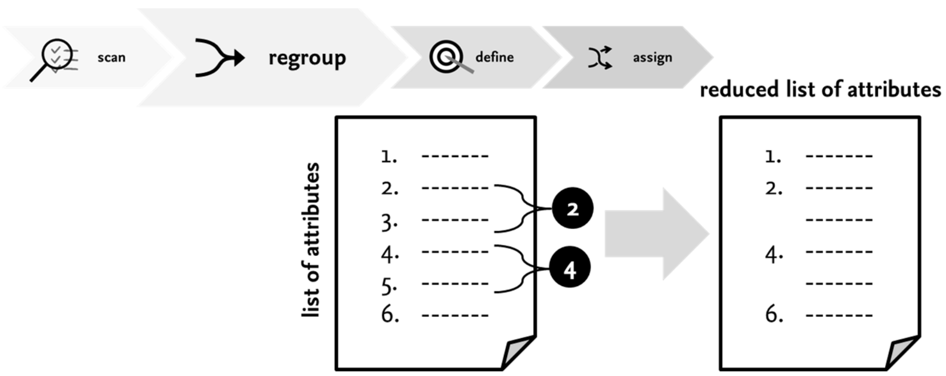


Figure 4-8 Step 2 of the identification of final attributes: regroup

For the example, an English and a German collection are presented to demonstrate the regrouping step alongside the treatment of translations. The German collection is provided by Ponn (2007) as a paper-based version. In Figure 4-9 this collection is represented on the left-hand side. The English one is also a paper-based one published by the Design Council (in the middle in Figure 4-9). On the right-hand side, an exemplary list of reduced attributes is shown. Please note that the numbers in the black circles in this figure do not match the numbers of those in Figure 4-7 (first step). Following the numbers, the first attribute is the method name, which is the same in both collections. The second attribute is called "Kurzbeschreibung" meaning short description in Ponn, the Design Council collection titles "What is it?" As the content is related, these attribute names are put together as one attribute in the reduced list. The illustration (3) is listed as one attribute. The same procedure as for (1) and (2) is applied for (4), which is "Zweck" (aim, purpose) in German, and "Aims" in the English collection. All possible translations are noted, if there are multiple English equivalents. The selection of an adequate term is described in step 3. Finally, this example regroups the German attribute "Wirkung", meaning effect or outcome, with the one from Design Council named "What is the output?", in short, output. In Figure 4-9, the corresponding number is 6. The other numbers shown belong only to one of the collections and cannot be regrouped.

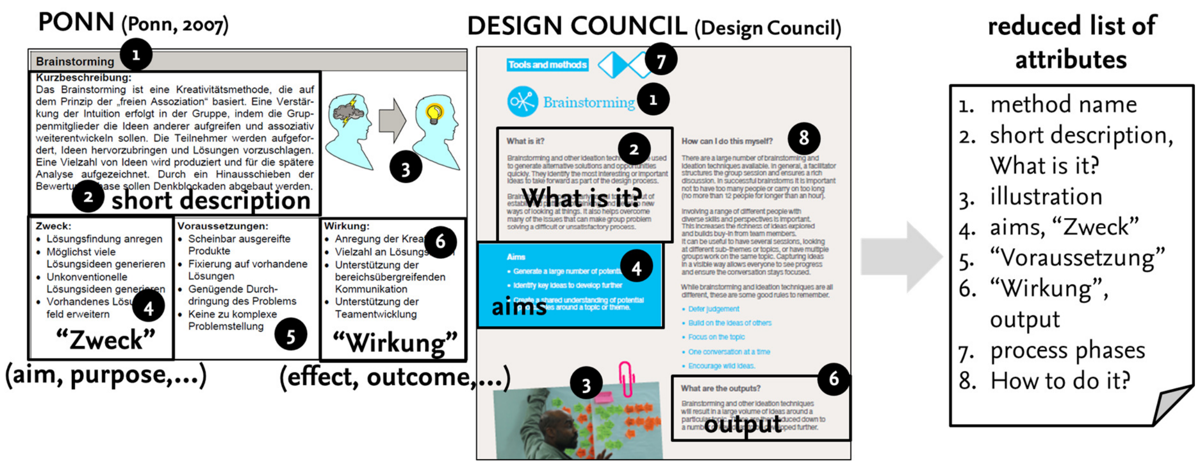


Figure 4-9 Example of the regrouping step to reduce the amount of attributes using the collection of Ponn (2007) and Design Council

After reducing the initial list of attributes according to the shown procedure, in total, 54 attributes remain on the list. These attributes will be defined in the next step.

3. Step: Define

The third step focuses on the formulation and the clear description of each attribute to enable the distinction between them. Figure 4-10 demonstrates the definition of the attribute's name with the example of the method aim, also named goals, objectives, Why?, etc. The criteria for the definition are the commonness of the attributes name, meaning the frequency of being named like this, the clearness of the name as well as the suitability for the German and English version.

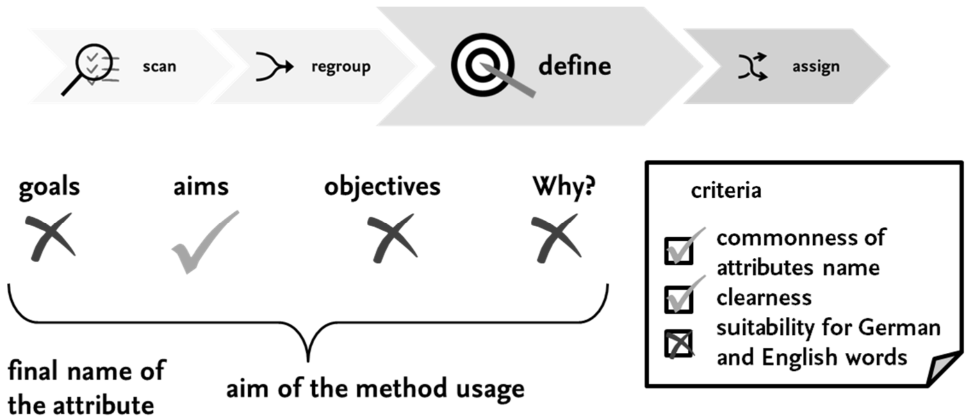


Figure 4-10 Step 3 of the identification of final attributes: define; shown with the aid of an example

Table 4-4 is an excerpt from the table containing the final attributes with their description how it is used in this thesis. Additionally, their origin, thus the collection or model where they originate, is indicated. The *method name*, for example, is part of all method collections and models. It is defined as *"Name of the method usually found in literature"*. The attribute *synonym* is only found in five method collections whereas the attribute *strength / advantages* can be found in several collections. Some attributes like the *effort of materials* are only derived from one single method collection, here: STRASSER (Strasser, 2004). The table also contains some collections named in brackets like MARTIN (Martin & Hanington, 2013) for *author of the method* and *background information*. This means that the attribute could not directly or explicitly be derived from the collection as it is, e.g. only partly considered or mixed with another attribute. In the case of MARTIN some methods contain background information and other methods contain the names of the author and no further background. Thus, these elements are later assigned to the attributes which is explained in the next step 4.

Table 4-4 Excerpt from table of final attributes with description and origin

cluster	attribute	description	element of following collections and models
method specific	method name	Name of the method usually found in literature.	all collections and models
	synonym	Further method names found in literature which can be used synonymously.	DOBBERKAU, MAP-TOOL, MEPORT, PM, WIPRO
	strength / advantages	Strength as well as advantages show positive aspects of the method, mainly compared to other methods or compared to fulfilling the task without a method.	DMF, EVERSHEIM, GINA, INNOFOX, INNOWISSEN, IPH, KUM, MAP-TOOL, MEPORT, PM, WIPRO
	effort of materials	The effort of materials indicates the amount of materials in general to provide for the method	STRASSER
	author of the method	The author of the method itself can reveal the way to original literature on a method.	EVERSHEIM, (MARTIN)
	background information	Background information on a method can be the history of the method, further interesting facts or other information not matching the other attributes.	BIRKHOFER, (MARTIN), PM

As previously introduced, the attributes are clustered into four groups: method specific, task / situation specific, team / user specific and additional content and tools. This enables a better focus on certain clusters on methods in the analysis. The complete tables with all attributes, descriptions and origins can be found in Appendix A1 by clusters. Figure 4-11 gives an overview of all attributes derived with their finally selected names.

method specific	method name
	synonym
	description / portrait of method
	short description
	illustration / picture
	procedure
	notes (regarding procedure)
	picture of procedure / flowchart
	strength / advantages
	weaknesses / disadvantages
	materials required
	models obtained
	effort of materials
	related methods
	synergies with other methods
	variants or adaptions of method
	adaptability of method
	author of the method
	background information
	literature on method
	preparatory steps
	preparatory effort
	training effort
	time requirements / effort
	continuous time requirements
	ratio: benefit/effort
	relevance of method

task / situation specific	method classification
	process phase
	general design activities
	aim of method usage
	complexity of upcoming task
	input / problem
	output / results
	orientation of results
	product type or domain of application
	size of company
	suitability for open innovation
team / user specific	team size (group <-> individual)
	roles within team (e.g. moderator)
	qualification of team
	experience with method usage
additional content and tools	multilingualism
	help function and support
	accessing possibilities (filter, selection criteria)
	provision or links to tools and templates
	practical examples (own upload)
	video tutorials / method videos
	commentary function
	evaluation function
	links to consultants or support
	presentation / download for training purpose
	content overview
	keywords

Figure 4-11 Complete list of final attributes for the analysis

4. Step: Assign

After deciding on the final attribute names, each element of a method description from the existing collections and models has to be assigned to the newly defined attributes. Basically, the reduction of step 2 can be used to assign the elements. In some cases, the creation of the final attributes allowed to assign better fitting attributes than originally named by the authors or as it was identified in the first and second step. An example is the attribute *experience with method usage* within the method collection KUM: At first, this attribute was listed as *evaluation function* as it is described as evaluation ("Bewertung") within the method description. By having defined the first named attribute from another method collection, the assignment to this attribute was more convenient. This procedure is demonstrated in Figure 4-12.

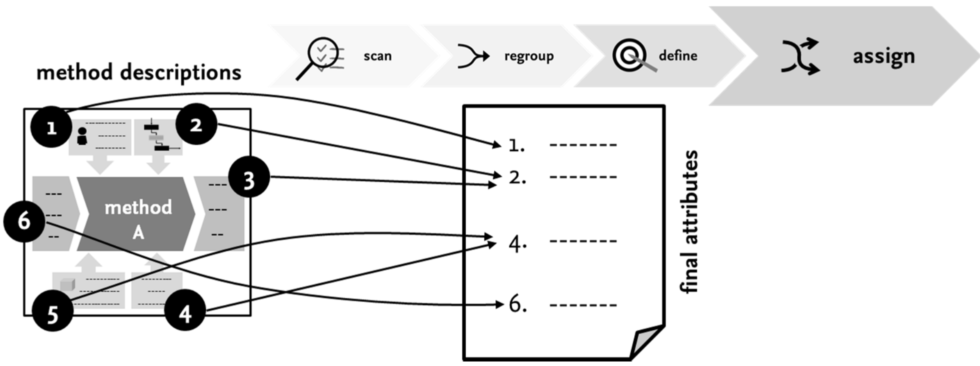


Figure 4-12 Step 4 of the identification of final attributes: assign

With the fourth step ends the preprocessing for norming the relevant attributes. These will be used within the analysis of existing collections and, furthermore, for the development of a new method description model focussing on the method user or team and its characteristics.

4.2.1.3 Types of access for method provision

Another preparatory step is the identification of existing access types for method provision. The procedure to create a list of possible access types is simple: all method collections are scanned regarding their access options. Paper-based and web-based versions are considered separately because in general web-based versions offer a wider range of access types compared to print media due to the possibilities provided by digital tools. Even though there are some paper-based method collections online available as PDF documents they are handled as if they were printed versions. In total, four access types for paper-based collections and eight types for web-based ones can be found in existing method provisions (see Table 4-5).

Table 4-5 Overview of different access types for method provision

paper-based	web-based
▪ via matrices ▪ via lists ▪ via graphical mapping (like process) ▪ via further mapping technique 	▪ via filter (filters list regarding applied filters) ▪ via search options (selecting multiple options and getting results) ▪ via user-defined text ▪ via lists (e.g. as ABC list, as tiles arranged) ▪ via matrices ▪ via questions ▪ via examples (suggested methods for an exemplary situation) ▪ via (process) models

For example, matrices that match process phases or general design activities to methods are commonly found in paper-based collections, but also in single web-based ones. Lists of methods are the main access type for both, paper- and web-based method provision. Furthermore, graphical mapping techniques like assigning methods to a process model or other mapping techniques are used within paper-based versions. For web-based collections, the use of relevance filters and reduction filters also referred to as search options in this work is quite common. In this case the difference is that relevance filters display a list of all methods showing those results matching the filter criteria first; reduction filters or search options allow also the selection of multiple options but display only fitting search results, thus, a reduced list. There exist some variations of these filters, which is why many collections will provide one of them or even both. Moreover, user-defined text searches and predefined questions are additional access types for web-based collections. Similar to the paper-based versions, (process) models and other graphics are used to assign methods. Finally, one collection offered exemplary tasks and solutions to select a method.

The assignment of method collections to access types is performed in the analysis in Section 4.2.3. Besides these general access types, the access via method description attributes will be analysed because attributes with predefined values are suitable for selecting methods.

4.2.1.4 Formalities for evaluating method provision approaches

The last step of the preprocess is the definition of formal criteria, in the following called formalities, to evaluate the method provision approaches regarding general, content independent aspects in a standardised manner. As both, method descriptions and method access, will be analysed, formalities suitable for both are preferable. Moreover, individual formalities for each analysis are added to complete the set of these formal criteria. The formalities can be mainly derived from literature on problems and barriers of method application and method provision. An overview of the formalities derived in the following is represented in Figure 4-13.

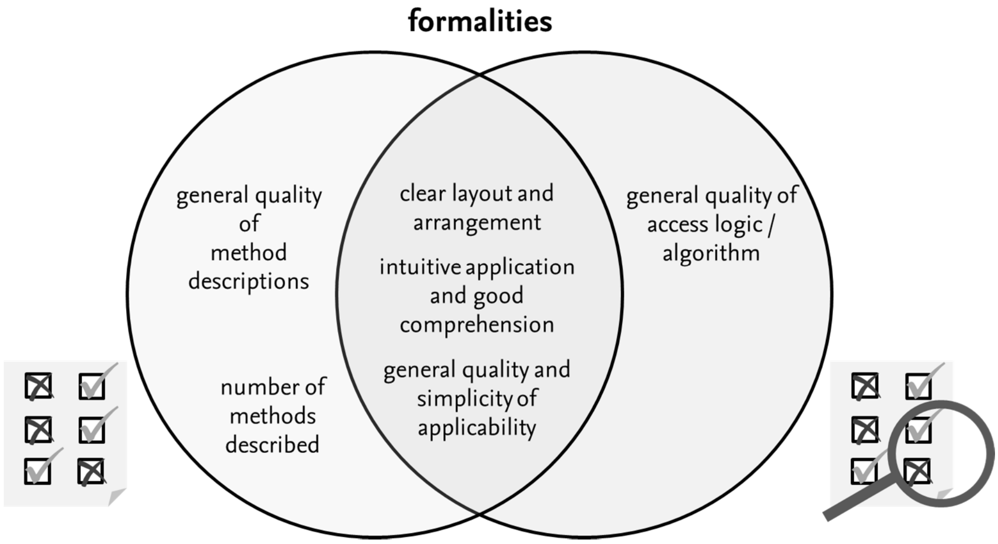


Figure 4-13 Formalities for method descriptions and method access

Beckmann et al. (2014) reviewed literature regarding requirements and shortcomings of methods and their transfer to practice. It is assumed that these requirements do not only match with engineering designers from industry which was the focus of Beckmann's work but also with students within design education. One of the major requirements is an efficient application. It shall be simple and intuitive to apply a method (Beckmann et al., 2014). Thus, the method provision has to have an *intuitive application and good comprehension*. To support this formal aspect the representation needs a *clear layout and arrangement*

(Hubka, 1983). This means that the structure is clear and uniform for all method descriptions or the method access; it is clearly arranged. An example is the usage of filters arranged in a manner that they are immediately recognised as filters. Based on this the *general quality and simplicity of the applicability* of method descriptions as well as of method access possibilities is another formality chosen to evaluate the method provision approaches. This formal aspect focuses more on the way to apply the method collections or the access possibilities like filters. Thus, this aspect evaluates the interaction of the user with the provision approaches. The idea is not to mentally overtax the users so that they can focus on the method to learn and without having to additionally struggle with the method collection or access. Furthermore, the *general quality of the access logic or the access algorithm* on the one hand and the *general quality of a method description* on the other hand evaluate the overall function (description or access) of the method provision approaches. On the level of the description, mainly the content of the descriptions is judged. The focus on main tasks, no theoretical overload and limited abstraction of the descriptions of the methods are relevant aspects. For method access the considered aspects are comprehensibility and consistency for access logic or algorithm and whether the algorithm works properly. Finally, the method descriptions are evaluated regarding the *number of methods described* within one method provision approach.

4.2.2 Analysis of method descriptions

In this section, the analysis of the method descriptions is specified. The aim of the analysis is to identify relevant attributes that focus on the method user and the team, e.g. if the team collaborates locally distributed. For the concept of a team-oriented method provision tool, well-described or well-presented method user and team attributes in existing method provision approaches will serve as an example. They also serve the purpose to create further method team and user specific attributes (see chapter 6). As mainly, but not excludingly team and user specific attributes are part of the team-oriented method provision tool, method, task and situation specific attributes as well as additional content and tools will be analysed in this section, too.

In the following part the realisation of the analysis as well as the scale for evaluation are described and then followed by the presentation of results.

Realisation of the analysis

Evaluation tables as shown in Figure 4-14 are used for the analysis. Five columns represent the formalities and the four clusters: method specific, task / situation specific, team / user specific, additional content and tools. The rows contain the method description models and collections, which are sorted regarding their provision format (paper- or web-based version). The basis for the evaluation of the method collections are up to four different methods within the collection using also the Brainstorming method as reference method over all collections.

The evaluation of each attribute or criterion for each method collection or description model was performed by four engineers and engineering students holding a master's or a bachelor's degree from the Institute for Engineering Design (TU Braunschweig) with expertise in the field of systematic design and design methods. To reduce strong subjective opinions the rating results were averaged. If they were ambiguous they were discussed and rated separately by the experts. The experts diligently rate the method description; some subjectivity cannot be completely ruled out.

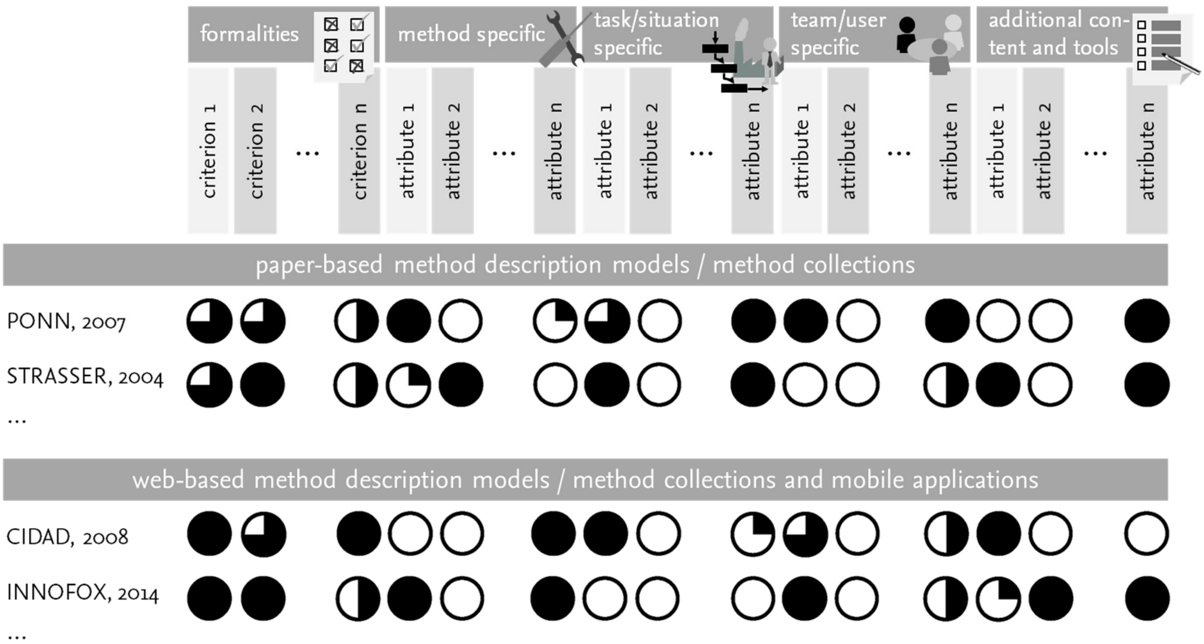


Figure 4-14 Schematic arrangement of the evaluation tables for the method description analysis

Scale

The scale used for the evaluation of both the attributes and the formalities is a five-point scale. Table 4-6 gives an overview of the meaning of each point on the scale for evaluating the attributes, evaluating the formalities and the number of methods within a method collection. Circles are used to represent the five-point values in Figure 4-14 and in the first column of Table 4-6. A blank circle stands for »0« and a completely filled circle for »1«. The values in between are consequently defined by steps of 0.25, which is important for the interpretation of some of the following graphs regarding the occurrence of attributes.

It is important to note that the evaluation of the attributes considers different aspects like the completeness (»0.25«), the suitability (»0.5«) and the representation (»0.75«). Each level on the scale can only be reached if the previous aspect is fulfilled. The order of these aspects can be justified as follows: if only single methods are described with the attribute, the evaluation is harder and more imprecise due to the lower basis (completeness). If the meaning is not fitting, then the evaluation is less comparable to others (suitability). The comprehensibility is finally the last aspect to fulfill when the content matches.

Table 4-6 Scale for the evaluation of method descriptions

symbol	evaluating attributes	evaluating formalities	no. of methods
○	not available	very poor	0
◔	partly or for single methods/elements available	quite poor	1-10
◑	available but not matching the meaning of the attribute completely	medium	11-30
◕	available but no comprehensible or adequate representation	quite good	31-99
●	completely with all relevant information available	very good	more than 100

To make the evaluation more transparent an example for each value on the scale is shown in the following:

The first value is always given when the attribute in question is not available in the method description. The Process-oriented Method Model (Birkhofer, Kloberdanz, Berger et al., 2002) receives the first value for the number of methods described with the help of this model because there is no complete method described with it. The second value is exemplarily given for the attribute *illustration/picture* in the collections INNOFOX (Institut für Produktentwicklung, Karlsruher Institut für Technologie, 2014), INNOWISSEN (SPP GmbH, 2004) and MAP-TOOL (RPK - Thomas Paral, Karlsruhe, 2000) because there are illustrations or pictures for single methods but not for all of them. There seems to be no recognisable scheme when an illustration is provided and when it is not.

For the higher levels on the scale, the MEDIALAB collection is used to demonstrate the evaluation (see Figure 4-15). The third value is given for the attribute *input/problem* as it is described when to apply the method - not necessarily, what possible inputs or problems are. For some method descriptions the corresponding content matches the attribute *input/problem* resulting in »0.5« points received. The fourth value is demonstrated with the attribute *classification*: this attribute is completely available but it is very small in representation and only when compared to other methods it becomes comprehensible. The completely filled circle, the fifth value, is exemplarily given for the short description because it is well-presented and always similar for all methods contained in the collection.

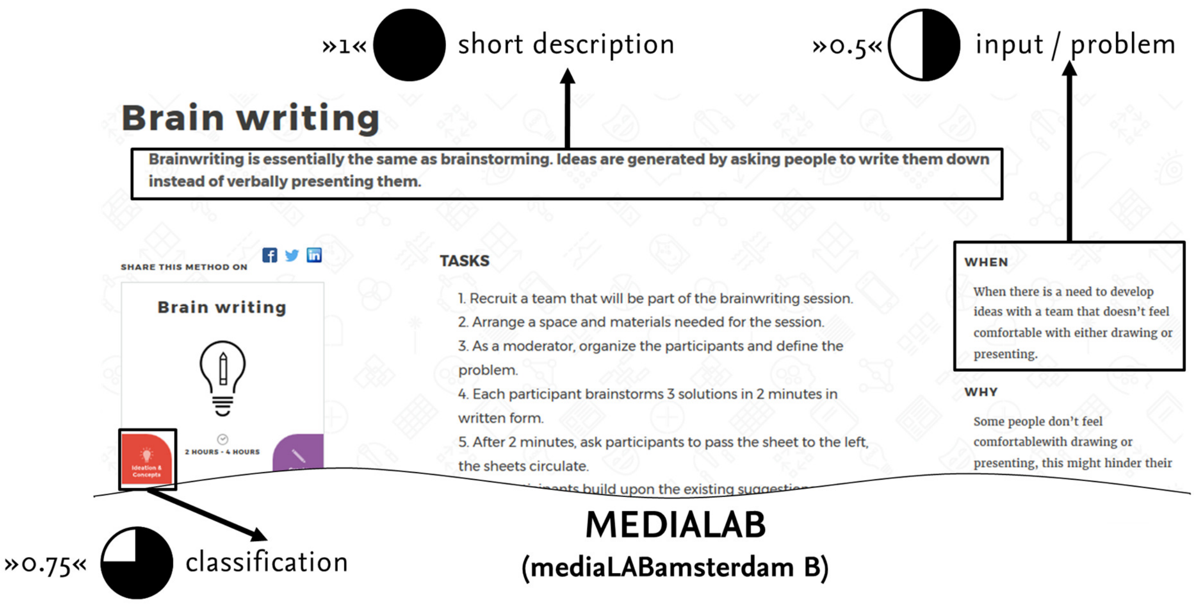


Figure 4-15 Examples for the meaning of certain points of the evaluation scale using the collection mediaLABamsterdam B

Results of the evaluation

On the next pages, the outcome of the analysis in terms of the resulting numbers counting the evaluation results (»0« to »1« points on the scale) is described cluster by cluster. The focus is on outcomes to draw a conclusion later in Section 4.4.1 and gather requirements. The final tables with the complete evaluations can be found in Appendix A2. The clusters as well as the formalities are separately printed in a table.

Method specific attributes

Figure 4-16 represents the attributes from the cluster method specific attributes over the sum of the evaluation results from the 25 collections and models rated with values from »0« to »1«. The *method name* is included in every method collection and model so that the corresponding sum is 25. The second most used attribute is *procedure* with 20 points. Thus, *procedure* seems to be a relevant attribute for almost all authors of method collections. This corresponds to the findings of Geis, Bierhals et al. (2008) who recommend to present a concrete step-by-step procedure. This is not the case for all collections and models.

The next most used attribute is *literature* within 18 collections, which could be an indicator that many of the collections do not claim to provide all relevant knowledge to apply the methods described. Subsequently, *description*, *illustrations* and *short description* follow with 12 to 15 occurrences, which is about half of the analysed provision approaches. It is noticeable that illustrations are often used in method collections describing design thinking methods whereas engineering design methods are rarely illustrated. In addition, only a few method collections and models provide a *description* and a *procedure*. Oftentimes, the *procedure* is implicitly described in the *description* like in WIPRO (TIM, 2013). Further attributes rated with at least ten points are *strength* and *weaknesses* having each eleven points as well as *related methods* with ten points. *Time requirements* and *required materials* for the method application are rated between seven to eight points while time and material needed are often hidden in textual descriptions and not indicated separately.

All things considered, the method specific attributes focus mainly on the general description and the procedure of the method. Only few collections separately indicate additional information on the concrete application. This information is then provided apart from the general descriptions.

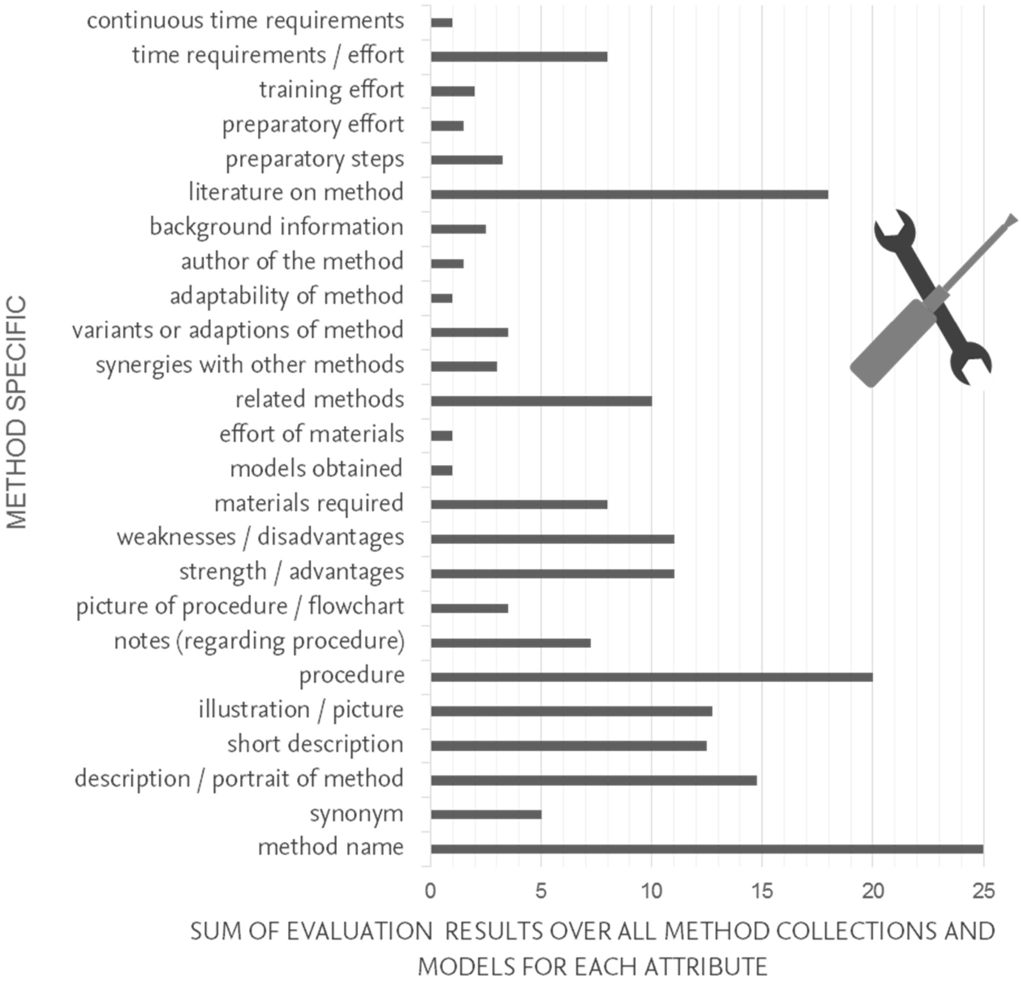


Figure 4-16 Result of the analysis: attributes from the cluster method specific shown over the sum of the evaluation results from all method collections and models

Task and situation specific attributes

The analysis of the task and situation specific attributes is combined with the team and user specific attributes in Figure 4-17. It reveals a primary focus on the method *output* with 13 points. This is also mentioned as one of the relevant aspects for designers in practice when looking at methods (Beckmann et al., 2014). The *input* can be found in fewer collections with 11 points. Thus, there seems to be no need for having *in-* and *output* in the same method collection and model because some of the method collections and models do only provide one of these attributes. The attribute *aim of a method usage* has about the same score as *in-* and *output* but it is not even used in half of the analysed method provision approaches. The aim is described within the general *description*, the *general design activities* or the *short description* in some cases. Further often used attributes are the *general design activities* (10 points), the *process phase* (about 10 points), and the *method classification* (about 10 points). Only one occurrence and, thus, one point have the *suitability for open innovation* within WIPRO and the *complexity of the upcoming task* in STRASSER.

Team and user specific attributes

The team and user specific attributes are in general rarely found in method collections and models. The most used ones in this cluster are the *role within a team* and the *team size* respectively, giving the information whether a team or an individual person is needed. Both attributes are rated with 6 points with very different qualities in each collection, which results in very few completely filled circles in the table. This fact is surprising because some authors emphasise the importance of the method user, e.g. Badke-Schaub et al. (2011) or Ponn (2007).

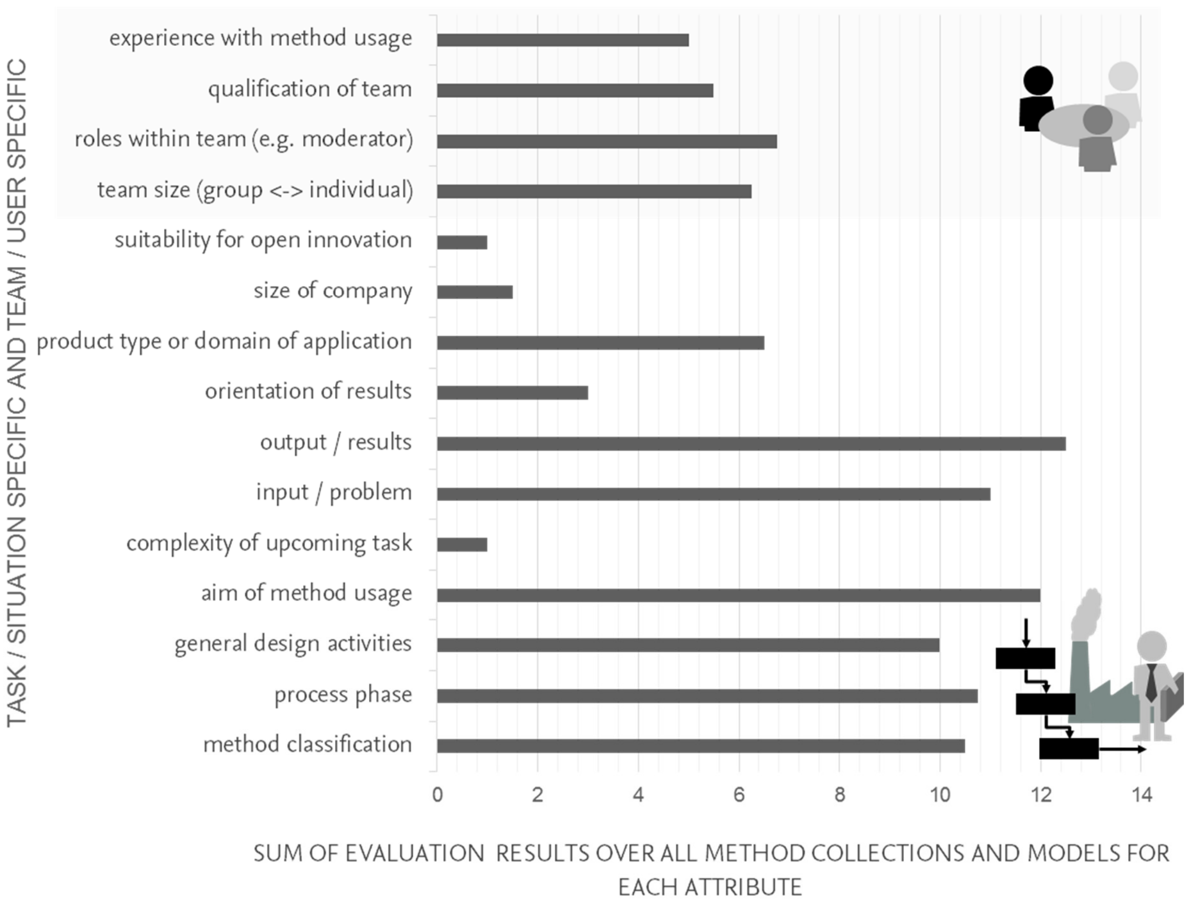


Figure 4-17 Result of the analysis: attributes from the clusters task / situation and team / user specific shown over the sum of the evaluation results from all method collections and models

Additional content and tools

The most important attribute within the cluster additional content and tools is the availability of *accessing possibilities*. Only one collection is rated »0«-point and two models that do not properly show the access possibilities are rated as »0.25«-point; the remaining 22 collections provide filters or other access criteria to select a suitable method. Nevertheless, the sum in Figure 4-18, showing the results of the analysis for the corresponding cluster, is about 15 points. This means that many *accessing possibilities* are not rated well. A detailed evaluation of the method access is, therefore, presented in the following Section 4.2.3.

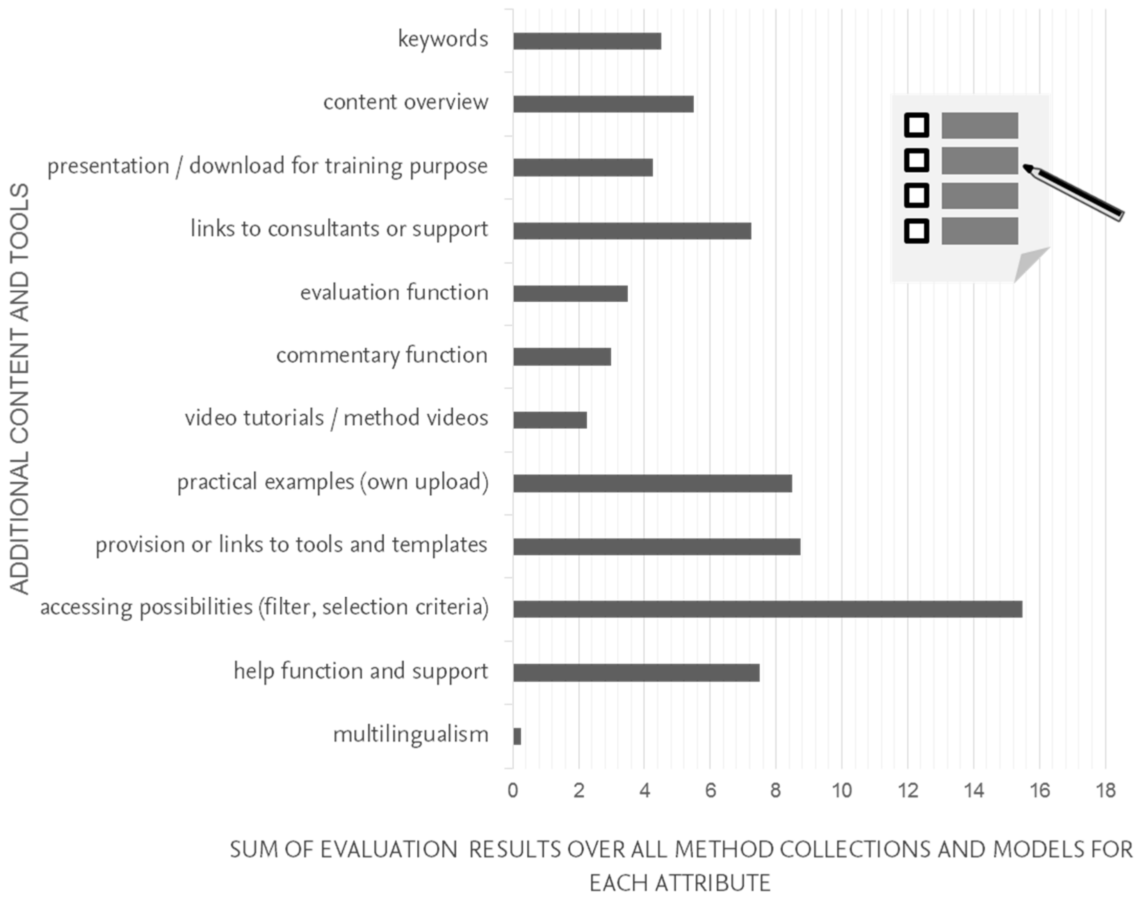


Figure 4-18 Result of the analysis: attributes from the clusters additional content and tools shown over the sum of the evaluation results from all method collections and models

Tools, templates or links to tools as well as *practical examples* are rated with more than seven points, but occur in 13 collections because the tools and examples are not always provided for all of the methods. *Help functions and support* and *links to consultants and support* are included completely in five method provision approaches and with lower rating in others. What is striking for distributed teams is that only one collection, the PM (Berleb

Media GmbH, 2015), provides the method name in another language (*multilingualism* equals »0.25«-point). In this case, the collection's language is German and the names are indicated in English as well. For internationally working teams it can be hard to train all of the team members properly except if all members are quite familiar with the training language that is the method collection's language.

These results are an answer to one part of the research question Q1. They show how method descriptions are provided currently. A summary of all of these results is presented in one overview in Appendix A3.

4.2.3 Analysis of method access

In this section the access possibilities in the existing method description models and collections are analysed. The aim is as before to identify the most used and best access possibilities to build on for the new concept focussing on teams and their characteristics. An overview of the ratings is presented in Appendix A4. The realisation was conducted in a team consisting of four method experts as described in the previous section. The procedure and the scale differ slightly from those used for the method description. Thus, they will be described in the following.

As analysed in Section 4.2.2 all but two method models and one method collection provide access possibilities. The respective collection is DMS (Stapelkamp, 2012), the two models are SPP (Braun, 2005; Gausemeier et al., 2004) and BIRKHOFER (Birkhofer, Kloberdanz, Berger et al., 2002). The two models cannot be evaluated in every category because it is not apparent how the access is realised. The categories considered for the analysis are the formalities, the types of access and the accessing attributes, thus, attributes that are used for access method descriptions. The formalities are rated as it was done for the method descriptions. The criteria used were derived in Section 4.2.1.4 as follows:

- general quality of access logic / algorithm,
- clear layout and arrangement,
- intuitive application and good comprehension,
- general quality and simplicity of applicability.

The types of access found in the existing method collections and models were introduced in Section 4.2.1.3. They are classified in paper- and web-based types. The attributes, which allow an access to methods, are identified by means of the analysis in the following. The scales used are related to the one of the previous analysis with regard to the symbols. It is a three-point respectively a two-point scale each from »0« to »1«. The access types are rated by considering if they are available in the collection or model. Some access types can be part of a different one. Using a process model for access, the model can be realised as a list of the process phases or as the model itself. In this case, the medium-filled circle (»0.5«) is chosen. The evaluation of the attributes used for the access can only have two results of a two-point scale: available or unavailable. The scales described are presented in Table 4-7. The scale used for the evaluation of the formalities corresponds to the one for the formalities for method descriptions (cf. Table 4-6).

Table 4-7 Scale for the evaluation of method access

symbol	evaluating types of access	evaluating attributes access
○	not available	not available
◑	access in another access included	-
●	available	available

4.2.3.1 Types of access and formalities

For the analysis of the formalities and the types of access a table is used like the schematic one of Figure 4-19. The structure is based on the one for the evaluation of the method descriptions: the columns contain the formalities and the different access types while the rows contain the collections and models.

The strong relation between the formalities is noteworthy. Generally, a clear layout and arrangement contribute to a better comprehensibility and, thus, to a better applicability. However, there are some exceptions. Good examples for the paper-based versions are

EVERSHEIM (Eversheim, 2003) and DESIGN COUNCIL (Design Council). The overviews in matrix format or with a graphical mapping technique allow for a quick and easy access. In contrast the collection of DOBBERKAU (Dobberkau, 2002) does not even provide the methods in an alphabetical order. This is why access without consulting the explanations around the collection in Dobberkau (2002) is quite difficult.

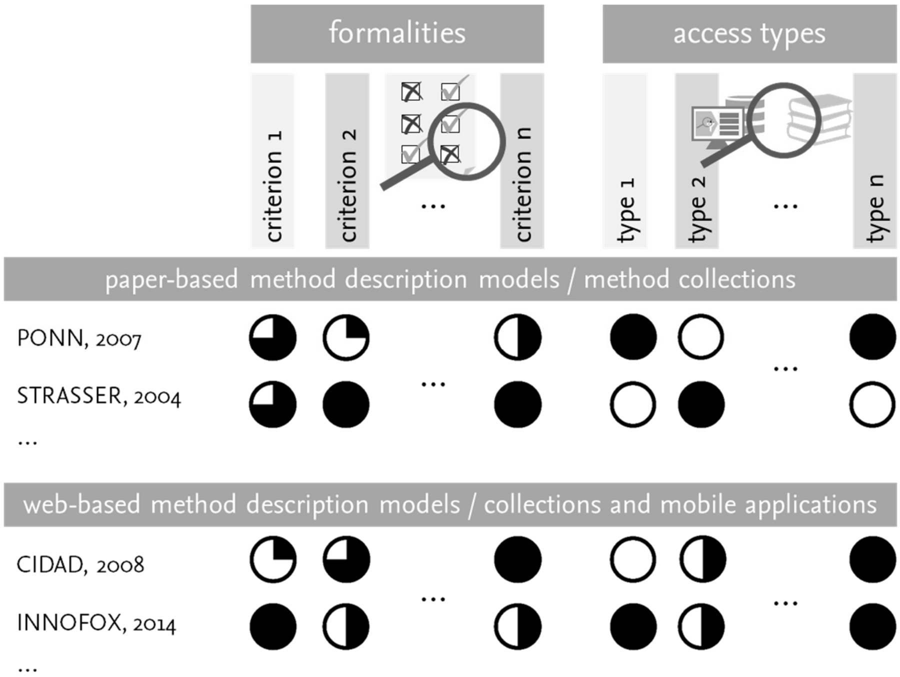


Figure 4-19 Schematic arrangement of the evaluation table for the method access analysis (formalities and access types)

For the web-based versions the wide range is remarkable. Some method collections only display lists with method names; others offer diverse filters and search options that are intuitively applicable. Arriving at the access types the paper-based versions mainly use lists and matrices to provide access to the methods. Due to the format these two types seem to be adequate. Matrices are rarely found in web-based method collections. Lists are quite common for online tools as they can be easily filtered. Thus, filters and search options are the next most used access types. Filters that display all methods regarding their relevance for the filter criteria are more often implemented than search options where a reduced list of resulting methods is displayed after submitting the search request. In summary, currently developed web-based collections in particular offer excellent access possibilities that can be adapted to a team focused method provision tool.

4.2.3.2 Attributes for access methods

Another interesting aspect for the aim of this thesis is the study of the attributes used to access the methods. The objective is to find attributes that help teams to identify suitable methods based on their characteristics. The analysis takes place in the same manner as the previous ones. A schematic overview is presented in Figure 4-20.

Counting the occurrences of attributes used as access possibility results in the diagram shown in Figure 4-21. The *method name* is the attribute to select a method in every method provision approach. Even when no separate access possibilities are provided, the access via the *method name* is still possible. About 15 collections assign methods to *process phases* for an easier access. Another nine method collections assign *general design activities* as well. Either in paper-based versions primarily as matrices or in web-based versions via filters, these attributes help to select appropriate methods for a given design task. According to literature statements, e.g. Birkhofer, Kloberdanz, Berger et al. (2002), Daalhuizen (2014), Lindemann (2009), the assignment to the design situation (process phase, task etc.) is recommended if the selection of methods that match the design situation should be assisted.

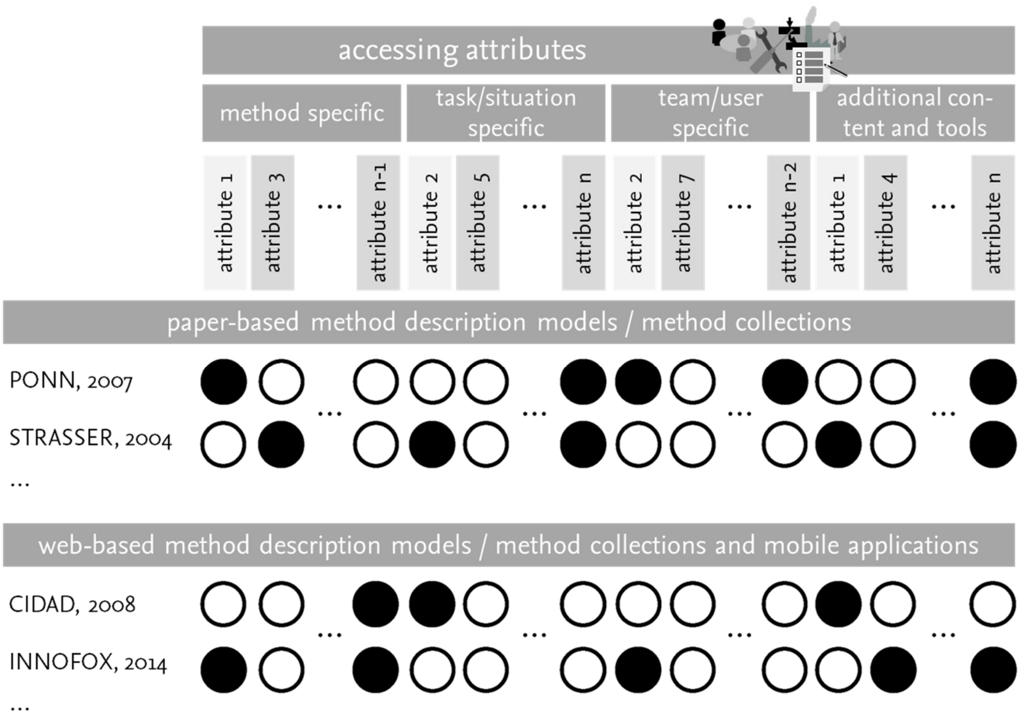


Figure 4-20 Schematic arrangement of the evaluation table for the method access analysis (accessing attributes)

A similar assistance can be provided by the attributes *method classification* and *keywords*, which occurred five times. The two last attributes worth mentioning due to the number of occurences are *synonyms* and *time requirements*. *Synonyms* equates to the *method name* in the way of access. *Time requirements* allow a new aspect of selecting methods. The time frame defines the design situation just as the attributes mentioned before (*process phase*, *general design activities* ...). From the cluster team / user, the *team size* is used twice; the *experience with method usage* as well as the *roles within a team* can be selected as access filters in the mobile application INNOFOX. In conclusion the usage of *time requirements* and the INNOFOX example will be considered in detail for the access of a team-oriented method access.

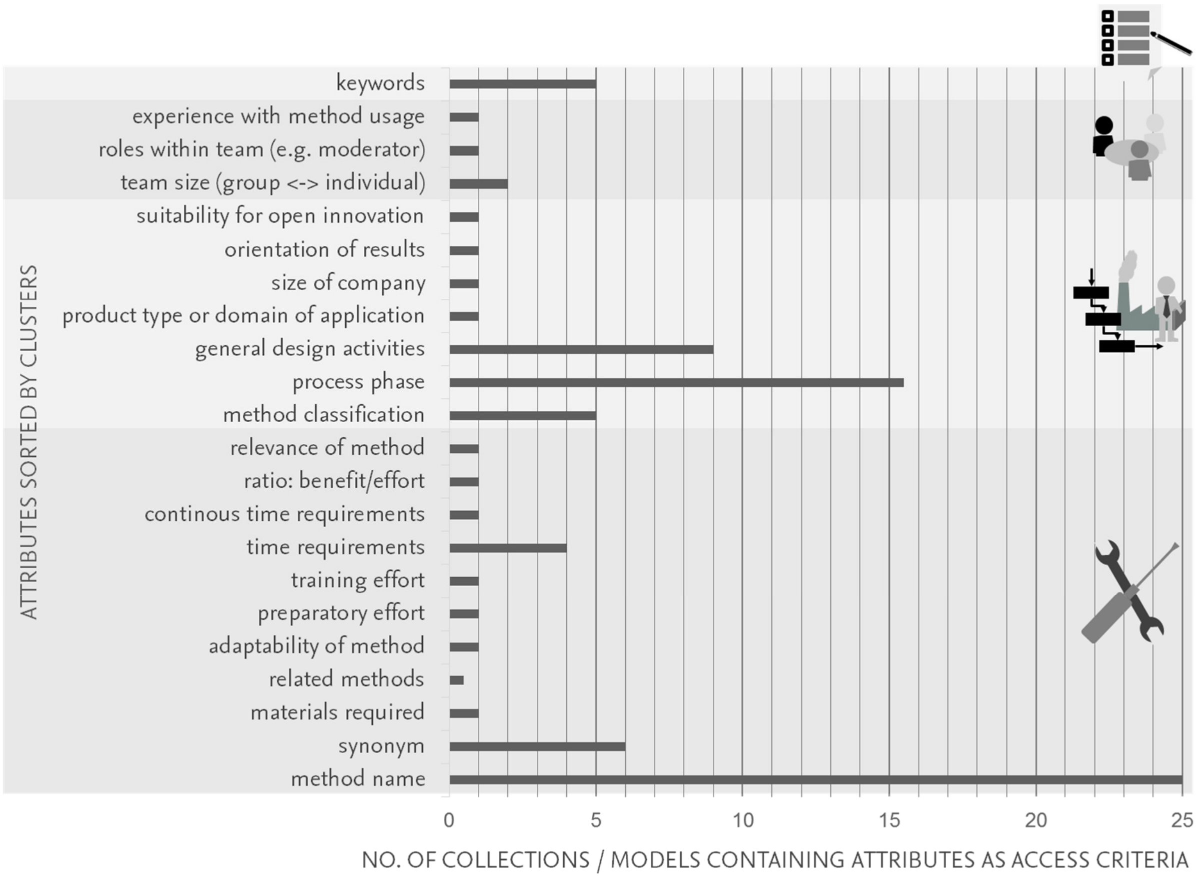


Figure 4-21 Result of the analysis: attributes shown over the number of collections or model containing these attributes as access possibility

The presented analysis of the current method access answers the second part of research question Q1 *"How are engineering design methods provided in existing method descriptions and collections?"* The results of the analysis of the method description and the method access give insights on the composition and quality of existing method provision approaches. These insights will be used in Section 4.4 to deduce requirements on a suitable method provision and to answer Q2.

4.3 Method provision in practice

Beside the theoretical review on what can be found in literature on design methods, results of the MuPro-KMU survey, e.g. Bavendiek et al. (2014), Moser (2014) or Vietor (2015), that have been introduced in chapter 1, will be used in this section to identify general requirements on method provision in practice as well as important attributes to describe the methods. The survey was conducted in a bigger company and in five SMEs. The results of the bigger company and the SMEs differ only marginally so the results will be presented together without any distinction. The participants of the survey were asked how a methodical support in their daily work should be like. The answers are clustered in four groups: amount of information, availability, individual flexibility and degree of complexity. Each group contains six to eleven elements. As an example, literature is an element of the group amount of information. The elements were rated on a 5-point-scale from »0« to »4« where »0« means »not needed/not appreciated« and »4« means »very much needed/appreciated«. The complete scale is presented in Table 4-8.

Table 4-8 Scale for the evaluation of the requirements on method provision

scale	meaning
0	not needed/not appreciated
1	rather not needed/not appreciated
2	neutral
3	rather needed/appreciated
4	very much needed/appreciated

Figure 4-22 demonstrates the results of the group amount of information. Except for two bars, namely *literature* and *evaluation/commentary function*, all elements were rated with two and higher. This indicates that almost all of the proposed content elements of method descriptions were highly appreciated. The highest rates received *tips for application* and *real product examples*. Thus, the relation to real applications is important for practitioners. Furthermore*, tutorials and videos* were appreciated for the description of methods. This is interesting because videos are only available in one collection (DMS) and in another one to some extent, see CIRCULAR (MacArthur, 2016). The method model of BIRKHOFER also suggests videos. The usage of videos for method training will be explained and discussed in chapter 5.

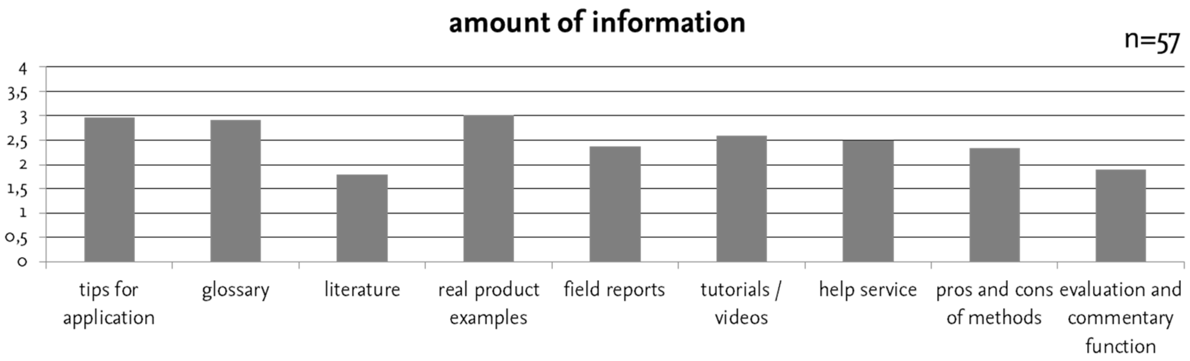


Figure 4-22 Results of the MuPro-KMU survey concerning the amount of information of method descriptions

Concerning the availability of method descriptions, a *web-based or digital access*, which allows simultaneous access for multiple users, is highly favored. *Access via mobile applications* is not much appreciated as indicated by a score of less than 1 point. Even the *paper-based versions* are rated higher with 1.8 points. Regarding *optional costs for better quality* no clear demand can be identified. *Optional costs for better quality* are slightly less appreciated than *no costs independently from the quality*. The results of this group are presented in Figure 4-23.

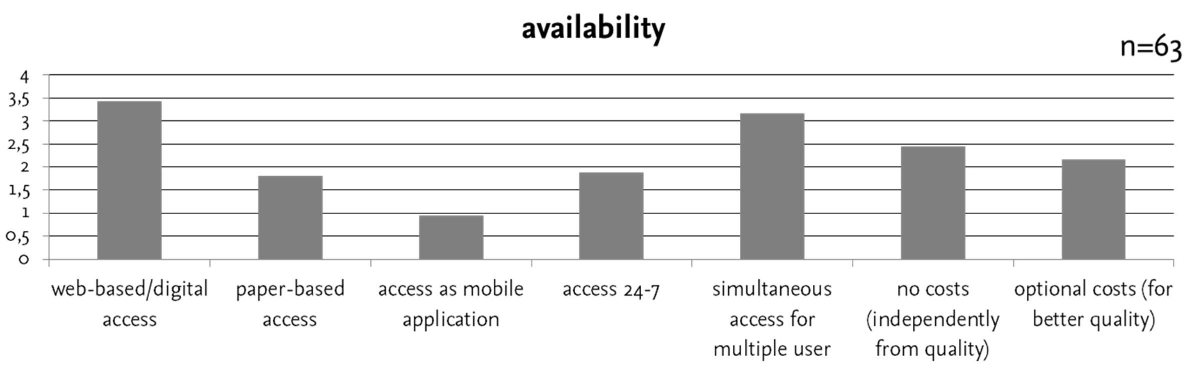


Figure 4-23 Results of the MuPro-KMU survey concerning the availability of method descriptions

Beside the availability, some questions were asked about the access and the flexibility of the method descriptions regarding individual needs and boundary conditions. Figure 4-24 illustrates the results of this group. The results are similar to those of amount of information. Almost all of the proposed access types like via *general design activities* or via *search options* are appreciated. Only two answers (*access via alphabetical list* and *suitable granularity*) are rated less than 2.5 points out of 4. The *possibility to set boundary conditions*, e.g. with a filter or with search options, is very much liked. Most important for the boundary conditions is the *design task* (3.2 points), followed by the *company* and the *user* (both 2.8 points). Compared to the existing access possibilities, where only single collections provide task and team / user specific access attributes, there seems to be a gap between what is available and what is wanted.

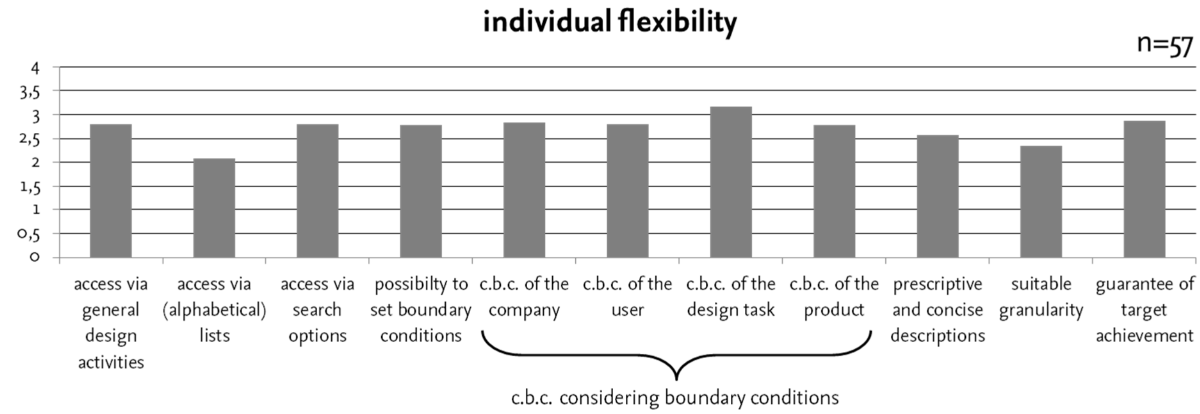


Figure 4-24 Results of the MuPro-KMU survey concerning the method descriptions' flexibility regarding the individual user

Within the group of degree of complexity, the elements *simple usage and applicability*, *low time effort for learning the method* as well as *structured and uniform method descriptions* are the most appreciated elements. The other elements are also more appreciated with more than 2.5 of 4 points. Only *high amount of information* and *theoretical background* is slightly below the neutral value. Hence, an easy to use method provision with structured and uniform descriptions that allow a quick understanding of the method is the favoured solution.

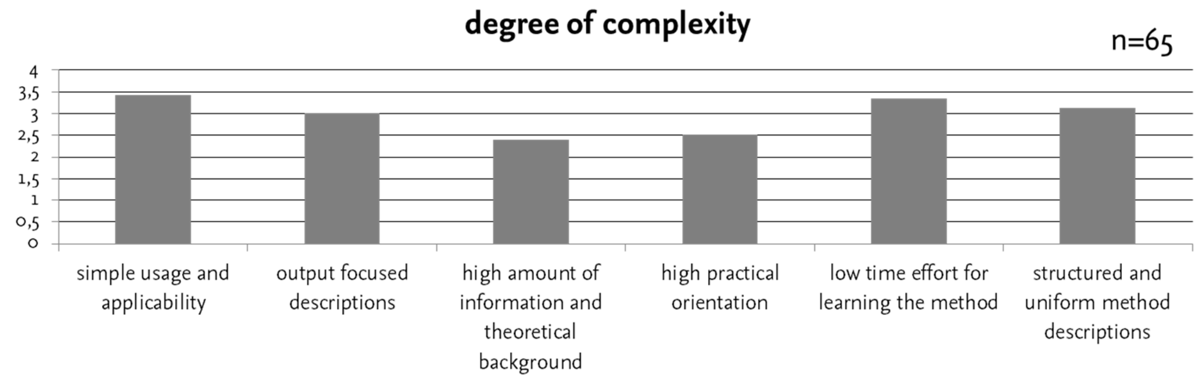


Figure 4-25 Results of the MuPro-KMU survey concerning the degree of complexity of method descriptions

In conclusion, the participants from practice were asked to weight the four groups regarding their importance. Each participant could assign 100 points in total to the groups. Thus, an equal weighting would be 25 points for each group. The results in Figure 4-26 show that the availability is the most important group whereas the amount of information is considered least important. A simple and easy to use method provision is also preferred compared to the other groups.

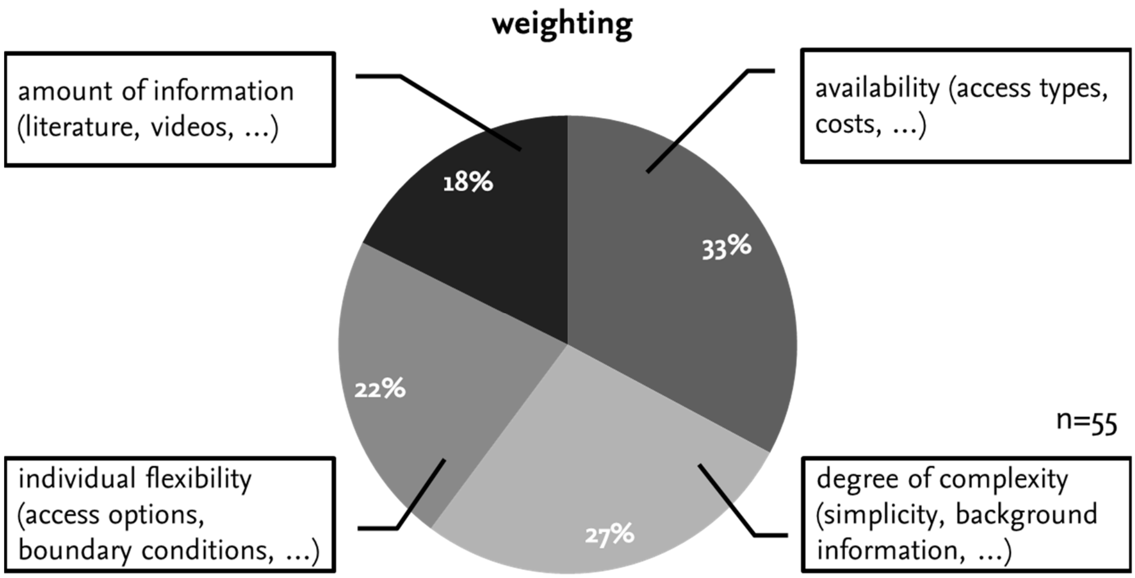


Figure 4-26 Results of the MuPro-KMU survey concerning the weighting of the four groups

4.4 Resulting requirements on method provision

This section will conclude on the one hand the analysis of existing method collections and models; on the other hand, it will conclude the findings of the presented survey from practitioners. Both parts will be considered regarding the method user or team. Finally, requirements on a team-oriented method provision will be deducted from the findings and summarized in a requirements list in Section 4.4.3 to answer research question Q2 *"What are requirements on a suitable method provision in engineering design?"*

4.4.1 Conclusion from the literature-based analysis

The analysis of 25 existing method collections and models and their access possibilities reveals 42 describing attributes and 12 additional contents and tools. Only the *method name* is included in all of the 25 collections and models. The *procedure* and *literature* on the method as well as a *description/portrait* of the method are also often found. Regarding the clusters method specific, task / situation specific, team / user specific and additional content, the most-presented attributes belong to the method specific one. Nine attributes appear more than ten times meaning 33 % of all attributes from the cluster; from the task / situation specific one, four attributes with more than ten appearances mean 36 % of them. There is one attribute from the additional content with more than ten appearances which is a share of 8 % of the attributes belonging to the cluster. The maximum appearance of an attribute from the team / user specific cluster is seven times, which is about a quarter of all method collections and models. Thus, there seems to be little relevance of the method user or the team within the existing method descriptions. This finding is illustrated in Figure 4-27. The considered method collections and models are placed in a diagram regarding their consideration of the method user or team. The ordinate is used to differentiate between method models, method collections and those which provide access possibilities that additionally take the team into account. The method access via team or user aspects is only partly possible in WIPRO and INNOFOX. The most aspects of the team or the method user are provided in PM, followed by INNOFOX and STRASSER. A partial consideration can be found in DOBBERKAU, DESIGNKIT and within the model of BIRKHOFER.

Despite these findings, it is important to consider the method user or the team as deduced in chapter 3. This begs the question: Are the most used attributes the best ones to describe a method in a way that is applicable for the user? If not, what are the best attributes to do so? Generally speaking, the challenge is to identify the focus of a good method description.

The MuPro-KMU survey, described in Section 4.3, gives first insights into what is appreciated by practitioners. This will be used as a starting point to answer the question. However, it has to be noted that many authors have dealt with these questions before and came up with some of the models or collections presented, e.g. BIRKHOFER. Nevertheless, there appear differences among the method models and collections and that for a good reason. Because every person, every engineering designer, every engineering student is individual, it can be assumed that there is no perfect method description for all of them. The individual learning preferences of the method user and team should be considered. Thus, a provision containing various elements but in a simple and structured way like proposed by Birkhofer, Kloberdanz, Berger et al. (2002) seems to be a suitable way. The relevance of different media and formats for training method knowledge will be examined in chapter 5. However, the method user plays an important role when learning and applying a new method. Hence, in the following Section 4.4.3, together with the findings from the survey in practice several requirements on a team-oriented method provision will be deduced from the above-mentioned findings.

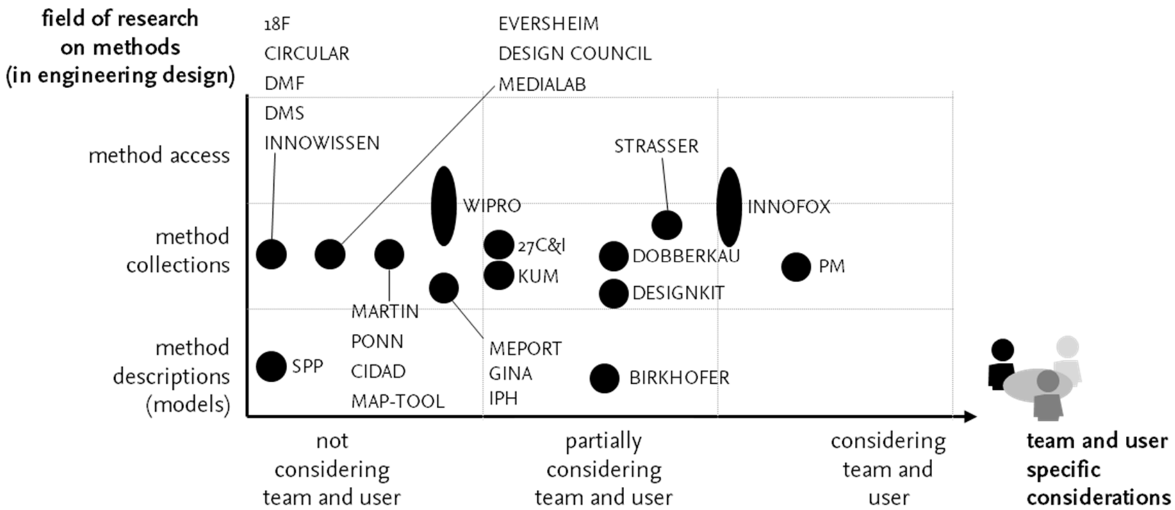


Figure 4-27 Placement of existing method collections and models regarding their content (axis of ordinates) and the consideration of the method user or the team (axis of abscissas); ovals are assigned to multiple topics on the ordinate

4.4.2 Conclusion of practical survey

The results of the MuPro-KMU survey reveal no clear preferences on most aspects like the amount of information or the individual flexibility. Most elements were appreciated by the practitioners, thus, no clear statements on the most important attributes can be made. This corresponds to the findings of the previous section. The best suiting attributes seem to depend on the method user. This again confirms the main assumptions A2 and A3 that method user characteristics influence the successful application of a method and also the method knowledge transfer in the form of the target group.

Some concrete requirements on method provision can be derived from the survey results: in general, there is a preference of a web-based or digital available method provision. Due to the increasing digitalisation of the work environment this demand of the users seems obvious. The web-based version is clearly preferred compared to a paper-based one. Remarkable is that a mobile application for the method provision does not seem to be needed or appreciated by the practitioners. In view of the fact of an increasing digitalisation, this is surprising. Among the existing method collections, there exists only one mobile application, which is called INNOFOX. Evaluations with students show great results of its application (Albers et al., 2015). Furthermore, a discussion with colleagues from the Karlsruhe Institute of Technology (KIT), who provide the mobile application, also shows a good acceptance within workshops with industry partners. A possible reason for the low values for the mobile application is that the existing infrastructure in bigger companies but also in medium-sized enterprises is oftentimes not yet designed for mobile applications. Thus, a usage outside of workshops is rarely possible for engineering practitioners. In addition, the survey participants demand structured and uniformly described methods. The method provision has to be simple and easily applicable. Furthermore, the time effort to learn a new method has to be low, which may indicate the time pressure in the engineering design process in the polled companies. Thus, the time spent to understand how the method provision tool, e.g. as a web-portal, works has to be minimized by an intuitively applicable system. If there are various formats redundantly provided to supply a suitable format for each user, the redundancy has to be obvious to avoid an overwhelming amount of information.

Furthermore, the definition of a method portfolio seems to be a possible way to reduce the amount of information provided. A predefined set of methods, e.g. about 20 methods, that are described in the identically structured way allows the engineering designer to select a suitable method more easily than from a method collection of 100 methods.

All of these findings and requirements are used in the following to create a requirements list for a team-oriented method provision approach.

4.4.3 Resulting requirements for team-oriented method provision

The conclusions from the literature analysis on method provision approaches and the results from the MuPro-KMU survey from practice shall be used in the following to generate requirements for a team-oriented method provision to answer research question Q2. The requirements are structured in a requirements list, which is available in its entirety in Appendix A5. The requirements list is structured in requirements for the following five groups:

1 formalities,
2 access to methods,
3 content of method descriptions,
4 additional content for the method provision tool,
5 training and learning methods.

Each group contains several requirements, which may be derived from the literature analysis (see Section 4.4.1), from the survey results (see Section 4.4.2) or from other sources like boundary conditions of the Institute for Engineering Design (IK) or the considerations of the team or method user involvement.

Table 4-9 presents an excerpt of the complete requirements list. As an example for the first structuring group requirement 1.1 demands “structured and uniform descriptions”. This requirement is derived from the survey results as a very important aspect. Thus, it is rated as essential and marked with an "E" for the requirement type. The number of methods that are included in the method provision concept is on the one hand depending on the methods taught in the engineering design courses at the university. Additional methods can be added, therefore, it is a minimum requirement that is marked with an "M". The selection criteria can be diverse, e.g. a general topic like creativity methods would lead to Brainstorming, Method 635 or Gallery Method whereas decision-making would rather lead to

Cost–Utility Analysis or a Point Rating System. On the other hand, the method portfolio for practice depends mainly on the company and its development process. As deduced in Section 4.4.2 it is reasonable to define a portfolio within a company to reduce the information for the individual. Thus, there is no definition for practice in the requirements list.

For method access, an overview of the method in a search result can be displayed using a short description. Hence, some of the analysed web-based method collections provide an overview and a short explanation. This is a reasonable optional feature for the concept for a method provision tool marked with an “O”.

The third structuring group defines the attributes that have to be included in the method description. They are mainly based on the literature analysis results. Another aspect is the consideration of user or team specific attributes. The corresponding attributes will be identified in chapter 6.

The fourth group contains requirements on additional content for the method provision tool that is not directly connected to the method descriptions and the access. Working through both the analysis results and survey results leads to the requirement 4.1. It contains the suggestion of literature on methods in general that is not related to the single methods. Literature was mainly not appreciated by the practitioners but most method collections provide literature. Thus, the requirement is optional (O).

In the last structuring group, the training and learning of methods, only one requirement is listed so far. It corresponds to the time effort for learning a method. This requirement could be derived from the survey results. Further requirements in this structuring group will be deduced in chapter 5 after analysing concepts for training and transfer of methods.

Table 4-9 Excerpt of the requirements list for a method provision tool

organisation:		product: method provision tool		date: 26/09/2017 version no.: 01	
		requirements list		editor: Bavendiek	
structure	**no.**	**name**	**data, values**	**req. type**	**source, comment**
1. formalities	1.1	structured and uniform description	same attributes for each method	E	MuPro-KMU survey
	…	…	…	…	…
	1.5	number of methods included	at least those from design education courses defined	M	IK
2. access to methods	2.1	web-based access	via a web portal	E	MuPro-KMU survey
	…	…	…	…	…
	2.6	overview of content in search results	using a short description (as attribute)	O	literature analysis
3. content of method descriptions	3.1	considering method specific attributes	method name synonym …	E	literature analysis
	…	…	…	…	…
	3.5	considering further team and method user characteristics	identify relevant characteristics/attributes	E	see chapter 6
4. additional content for method provision tool	4.1	suggesting literature in general	not bound to single methods	O	MuPro-KMU survey and literature analysis
	…	…	…	…	…
5. training and learning methods	5.1	low time effort for learning method	$t \lesssim 10$ min	M	MuPro-KMU survey

4.5 Reflection on research questions

The last section will be used to conclude and reflect on the research questions addressed in this chapter. Both questions could be answered in detail by the analysis and the findings from the survey in practice.

Q1 *“How are engineering design methods provided in existing method descriptions and collections?”*

- There exist many paper- and web-based method models and collections. All of the 25 analysed collections were directly accessed to experience the usage.
- Beside some unstructured descriptions mainly in book chapters which were excluded from the analysis it is common sense to describe methods in a structured and uniform manner.
- The method user is rarely mentioned. The expected research gap of a missing consideration of method user characteristics could be confirmed.

Q2 *“What are requirements on a suitable method provision in engineering design?”*

- Many requirements could be derived. Sources are common presentations of several method descriptions and collections. Further requirements originate practice. Though, neither common sense in research nor opinions in practice prevent misunderstandings regarding requirements. Thus, the requirements presented were reduced to a common denominator.
- The term “suitable” depends on the user of the method provision. A consideration of multiple approaches in terms of different media and formats when providing methods seems to be a good solution.
- The consideration of the method user is requested by the practitioners as boundary conditions of the method application. Adaptions of methods concerning these conditions are relevant.

5 Analysis of Training Approaches for Design Methods

"Knowledge is power. Information is liberating.
Education is the premise of progress,
in every society, in every family."
Kofi Annan, Ghanaian diplomat and Nobel Peace Prize winner

Methods are aids to solve daily challenges or even bigger problems in the design process. However, as presented in chapter 1, there are only a few methods known and applied in practice although many more are taught in the engineering design education. The question is: what reasons can be found for this discrepancy? First of all, the teaching formats at most German universities are not optimal due to great numbers of students (acatech, 2012). Most professors present the learning content within lectures mainly without interactions with students. Practical exercises are provided but frequently not to the extent needed. At some universities there are projects using exemplary design tasks like the KaLeP (Albers et al., 2000; Albers et al., 2004) or the design² (Sanchez Ruelas et al., 2012). Though, the general method knowledge transfer seems to be improvable.

The subsequent field of relevance in this thesis after design education is the application of methods in practice. Many authors claim a low acceptance of design methods in industry (Araujo, JR, 2001; Geis, Bierhals et al., 2008; Jänsch, 2007; Wallace, 2011). Weiß and Birkhofer (2006) distinguish three types of method knowledge transfer or method training for industry partners: seminars, bilateral projects and transfer workshops. Seminars are similar to lectures at universities. Projects aim at the development of a product or component or at the provision of services by the research partner. Normally, the methods applied in these projects are not transferred to other projects within the organisation (Weiß & Birkhofer, 2006). Transfer workshops focus on the provision of method knowledge and training of method application in a more general manner. The objective is to enable the participants to apply the methods to their daily work problems (Weiß & Birkhofer, 2006). However, the style of transfer workshops oftentimes resembles seminars with slides and moderation. The participants are seldom responsible for their learning experience as they only consume the knowledge presented. They are rarely able to transfer the methods onto their own daily problems.

The research question Q5 in this context is *"What are success factors and barriers for method knowledge transfer in design education and practice?"* The answer to this question helps to identify relevant requirements on method training and general method knowledge transfer. The requirements will complete the requirements list of chapter 4.

To obtain the requirements, the structure illustrated in Figure 5-1 is chosen. After presenting relevant terms and definitions (Section 5.1), multiple analyses follow. The analysis of success factors and barriers for method transfer from literature delivers first requirements (Section 5.2.1). The analysis of existing training concepts reveals insights on formats and media used (Section 5.2.2). These will be considered in correlation to the requirements from literature (Section 5.2.3). The final goal is the deduction of further requirements in regard to suitable formats and media for method transfer (Section 5.3). A reflection on the research question completes the chapter in Section 5.4.

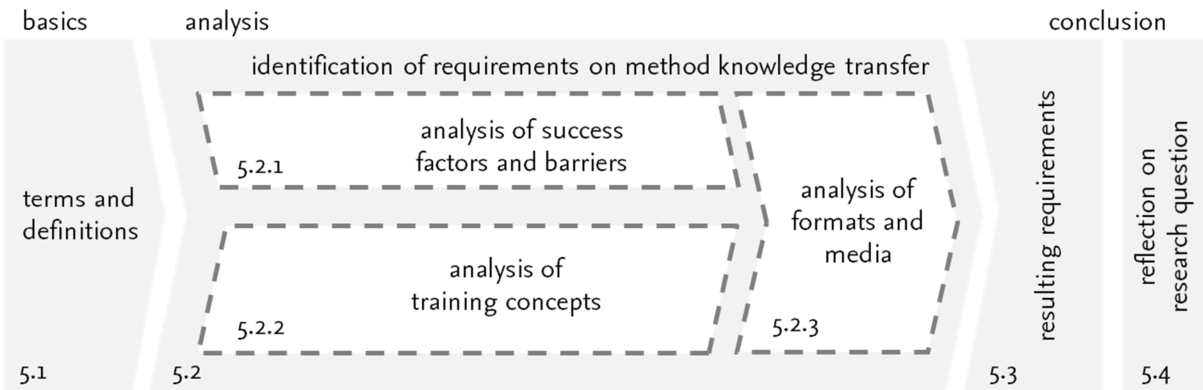


Figure 5-1 Schematic illustration of the chapter's structure

5.1 Terms and definitions

Besides the definitions given in chapter 2, the terms *method knowledge transfer*, *method training* as well as *format* and *media* will be defined for further understanding of this chapter. *Method knowledge* comprises all information and skills acquired to apply a method. According to Geis, Birkhofer et al. (2008) the methodical competence of a designer consists of expert knowledge like factual knowledge, choice of methods, adaption of methods, execution of methods and reflection on actions. Thus, the aim of *method knowledge transfer* is the successful transfer of all these abilities to the learner, be it student or practitioner. Oftentimes, the transfer of knowledge is accompanied by application and training of this knowledge. In this thesis, the terms *method knowledge transfer* and *method training* will be used interchangeably, even though *method training* is one technique of transfer in contrast to the general term *method knowledge transfer*. The different types of knowledge transfer or types of training will be called *format*. *Format* is defined as “the way in which something is arranged or set out” (Oxford Dictionaries, 2017a). Furthermore, different types of *media* can support the method transfer like texts, pictures or videos. Media is generally defined as “a means by which something is communicated or expressed” (Oxford Dictionaries, 2017b).

5.2 Identification of requirements on method knowledge transfer

To identify a set of requirements on method knowledge transfer in design education and in practice, three analytical steps are conducted. First, success factors and barriers for the method transfer and training are reviewed from literature. These factors and barriers are clustered and used to formulate requirements on the transfer. The second step is used to analyse existing training and transfer concepts regarding their content, media and formats as well as the target group. The revealed media and formats are correlated to the earlier defined requirements from literature. The aim is the identification of specific requirements for the design of training as well as for transfer media and formats.

5.2.1 Analysis of success factors and barriers for method knowledge transfer

Based on the description of success factors and barriers on method knowledge transfer and training in Section 2.3.3.3, several research works are analysed regarding their statements on barriers, obstacles of and problems with engineering design methods in practice. Some authors also deal with challenges of method training in design education, e.g. Geis et al. (2010). The barriers found were clustered in four groups following earlier approaches like Geis, Bierhals et al. (2008) or Lohmeyer et al. (2014): presentation of methods, implementation and support (in organisation), acceptance of methods and consideration of daily work.

Similar barriers were grouped, resulting in seventeen grouped barriers within the four clusters. Main sources for barriers are the following research works: Araujo, JR (2001), Andreasen (2003), Beckmann et al. (2014) and Beckmann et al. (2016), Jänsch (2007), Schneider et al. (2006) and Vietor (2015). A complete list of the barriers can be found in Appendix B1. Exemplary grouped barriers assigned to the four clusters are displayed in Figure 5-2.

cluster	presentation of methods	implementation and support (in organisation)	acceptance of methods	consideration of daily work
barriers	complex presentation	difficult to implement	advantages of methods not recognized	low flexibility
	too theoretical, too abstract	lack of management support and capacity	missing time for method use, tight project schedule	high effort to adapt methods
	prototype software tools only	lack of investigations into fitness, usefulness, benefit	no evaluation of results attained by methods	distance to daily work problems
	...	...	...	...
success factors	simple fitting methods	understanding company's needs	convincing people	flexible and adaptable
	focus on main task	planning change process/ implementation	teach theory but train methods	examples from daily work
	consider user, meet designers	meet design situation	mediate and quantify benefits	exercises
	...	...	...	...

Figure 5-2 Exemplary success factors and barriers for method knowledge transfer mainly in practice based on literature

Below the barriers, exemplary success factors are shown in Figure 5-2. These are grouped in the same four clusters as Beckmann et al. (2016) do in their research. Some of the success factors found in literature are formulated as requirements, some as commandments. A clear distinction is not always possible. Thus, all of these elements found are called success factors and gathered in one overview. The research works used to collect success factors are: Beckmann et al. (2016) and Beckmann et al. (2014), Birkhofer et al. (2005), Jänsch et al. (2006), Geis, Bierhals et al. (2008), Lohmeyer et al. (2014) and Lutters et al. (2014). The complete list of these factors is part of Appendix B1.

Some of the success factors were already formulated as requirements on method knowledge transfer by the authors (see above). The lasting success factors and also barriers were used to transform them into further requirements. In total, 22 requirements in the four clusters could be identified. These are presented in Figure 5-3. The sources of the requirements in means of success factors are also indicated in Appendix B1.

The requirements will be used in Section 5.2.3 to correlate them to media and formats of method training which will be deduced in the following section.

requirements on method knowledge transfer

presentation of methods	implementation and support (in organisation)	acceptance of methods	consideration of daily work
simple representation of methods	consideration of organisation's needs	involvement of designers in method selection	provision of adaptable/ modular methods
simple methods	reusable and extendible methods	provision of reflection and experience exchange possibilities	usage of realistic examples and exercises (from organisation)
focus on essential	planning of implementation	offer training/action possibilities	
focus on results	interdisciplinary change teams	fast transparent benefits	
consideration of different knowledge levels	pilot projects or/and usage of real design tasks	quick results and time saving through methods	
improvement, update and evaluation of methods	top management support		
software supported approaches (one database)	method champions (experts)		
	training and provision of support		

Figure 5-3 Clustered requirements on method knowledge transfer based on success factors and barriers from literature

5.2.2 Analysis of existing method training concepts

Besides success factors and barriers of method knowledge transfer, concepts for method training in design education (DE) and practice (P) as well as particularly concepts for method transfer from research to practice were analysed regarding media and formats used. Table 5-1 gives an overview of the concepts reviewed.

In total, seventeen concepts from different authors and/or different focus are included. The table lists the authors, the name of the concepts and the formats and media used. The main purpose of the analysis is the identification of formats and media utilized in the context of method transfer or training. In addition, the target group of the concept in terms of design education (students) or practice (engineering practitioners) is indicated in the last two columns of Table 5-1. Appendix B2 contains a table with an additional description of each concept. The references stated can also be consulted for detailed concept descriptions. The analysis tries to include many different concepts but is not exhaustive.

Table 5-1 Results of analysis of existing method knowledge trainings and transfer approaches (DE – Design Education, P – Practice)

author	name of concept	media and formats used	DE	P
Ahmad et al. (2014)	DG-MOTS (Design Game Matrix of Tool Selection)	game	x	
Albers, Walter et al. (2014), Reiss, Bursac et al. (2016)	InnoFox	mobile application, workshop	(x)	x
e.g.,Albers et al. (2000), Albers et al. (2004)	KaLeP (Karlsruher Lehrmodell für Produktentwicklung)	projects, virtual teamwork, feedback from experts (industry partners and research assistents)	x	
Beckmann et al. (2016)	Approach to Transfer Methods for Developing Modular Product Families into Practice	computer-based method description for presentation/selection (MPV), transfer concept		x
Birkhofer, Lindemann et al. (2001)	thekey Process	training concept	x	
Braun (2005)	Supporting Matrix	checklist matrix		x
Braun and Lindemann (2003)	Munich Model of Methods	transfer concept		x
Bucciarelli (1997)	Delta Design Game	game	x	
Geis, Bierhals et al. (2008)	Method transfer model	transfer concept		x
Geis, Birkhofer et al. (2008), Geis (2011)	BEMAP (Behavioral Marker in der Produktentwicklung)	training concept	x	(x)
Geis and Birkhofer (2009), Geis (2011)	Checklist for reflection	checklist		x
Geis (2011)	SAM model (Modell des situationsangepassten Methodeneinsatzes)	transfer concept	x	x
Jänsch (2007)	Checklist for training elements	checklist	x	
Lenhart and Birkhofer (2006), Lenhart (2008)	User Classification	documents (text, pictures), navigation	x	x
Reiss, Albers et al. (2017)	SPALTEN game	board-game in workshop	x	x
Reiss, Bavendiek et al. (2017)	Method videos	video	x	
Weiß (2006), Weiß and Birkhofer (2006)	Project Guide (as part of pinngate)	method portal for preparation and training	x	x

Regarding the format and media, mainly two superior types can be differentiated: training or transfer concepts determining the complete transfer or training process or single elements that are part of a greater process. Some authors provide a superior concept as well as single elements for the realisation, e.g. Geis (2011). Among the single elements, there are games, checklists, advice for the document design, videos or method portals, digital descriptions or method applications. The formats and media used are not correlated to the target group. There are, for instance, games applied in design education but also in workshops with practitioners. The transfer concepts from research to practice address the industry only. For the following analysis, the media and formats are mainly of interest and will be used subsequently.

5.2.3 Analysis of formats and media for method knowledge transfer

The next step aims at identifying further requirements on method knowledge transfer and training, especially focussing on media and formats of the training. The media and formats can roughly be divided into media and formats with primary focus on method provision, e.g. documents, videos, method descriptions in general, and with primary focus on the application of a method, e.g. games, workshops, projects. These media and formats are mapped to the requirements from literature in a matrix as presented in Figure 5-4. In the matrix's cells, there are hints and further requirements on how to fulfil the requirements using the corresponding media. Many cells could be filled by reviewing the existing training and transfer concepts providing already suitable solutions. Some cells cannot be filled reasonably. As an example, the requirements on "simple methods" cannot be addressed by media or formats but it is a requirement on the development of a new method. The completely filled matrix is part of Appendix B3.

The matrix serves the purpose to deduce some conclusions on method knowledge transfer and requirements, c.f. following section 5.3. The following conclusions could be identified as they occurred multiple times as hints in the matrix:

- only providing methods is not enough; application of methods is necessary,
- projects are a good way to apply methods, but prior knowledge transfer is needed,
- requirements on presentation on methods serve method provision, only marginally training and transfer,
- moderators or method experts are helpful for method application (training),
- training and application possibilities are very important,
- realistic examples or real tasks enhance the acceptance and relevance of methods.

Most of these conclusions are already postulated or addressed in earlier research. The proposed solutions for training concepts stress the importance of these findings in particular. Hence, the application of a method is the best training approach.

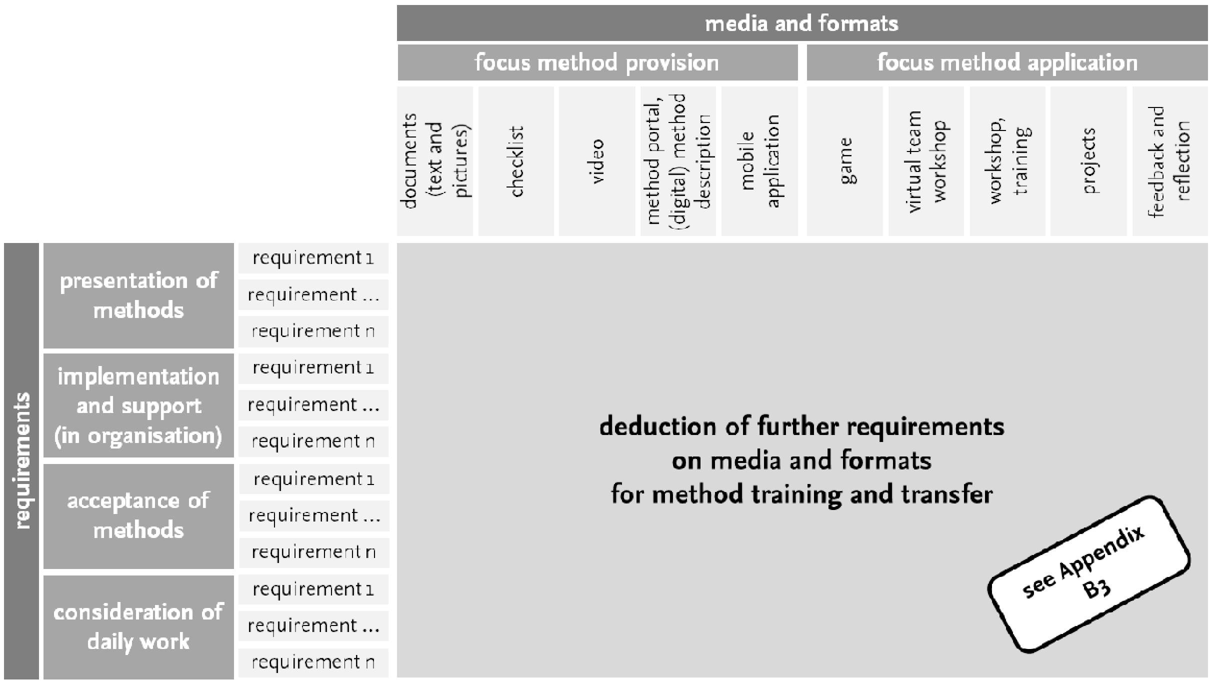


Figure 5-4 Mapping of requirements on method knowledge transfer and media and formats

Considering the target group of a method training, the main difference between practitioners and students is that engineering practitioners have the required product knowledge for real tasks. Students have to acquire product and method knowledge simultaneously. Thus, there are different requirements on training concepts for design education and practice (Birkhofer, Kloberdanz, Sauer et al., 2002). Subsequently, three groups of requirements were identified based on the conclusions: target group independent requirements, those for design education and those for practice. The requirements independent of the target group are:

- including reflection/feedback on methods and their application in training, but also in provision (e.g. as commentary function with reflective questions),
- reflection includes benefits, results and time needed,
- combining method selection (access in method portal/application) with training; participants can choose own workshop content,
- considering different types of learners (thus different media) and knowledge levels.

The specific requirements for practice deduced from the analysis build on existing requirements in literature. The requirements detail ideas on how to implement method training in the organisation. The requirements are as follows:

- identifying real tasks for method training prior to training and prepare training accordingly,
- identifying organisation's needs prior to training within separate workshop or interview with core team,
- including workshop before and after training for top management, interdisciplinary change team and method expert to plan implementation (planning training and further utilisation of methods, e.g. using checklists),
- using real tasks from company (see above).

As mentioned above, students need other training concepts than practitioners. Thus, the requirements on practice regarding the utilisation of real tasks can be translated into the following requirements for design education:

- using realistic examples from industry partners,
- using projects or other types of teamwork for method application.

Furthermore, motivation is maybe even more important for students than for practitioners as the last named can be convinced by benefits from method application. Students mainly have to pass an exam and tend to learn focussing on the exam only. Thus, two general requirements on education can be added:

- attraction and motivation through entertaining formats and media,
- attraction and motivation through diversification of courses.

Reflecting on these findings, it is difficult to apply all methods to be taught in design education within exercises or moderated workshops. A possible way is the selection of important methods and the transfer of knowledge on how to approach new methods. In practice, methods should be selected beforehand. The training then focuses on the application of those methods.

5.3 Resulting requirements for method training in design education and practice

In Section 4.4.3, requirements for method provision were deduced. Now, the requirements list shall be completed by requirements on method knowledge transfer and training. The origin of these requirements is literature. All requirements postulated in Figure 5-3 except for

- simple methods,
- reusable and extendible methods, and
- provision of adaptable and modular methods

which concern the methods itself and not their training are taken to the requirements list. The requirements from the cluster presentation of methods are mostly covered by existing requirements on the method provision (see chapter 4). Thus, there remain thirteen requirements from literature (see Appendix A5).

The second origin of requirements is the analysis of training media and formats from Section 5.2.3. Hereby, requirements for the design of media and formats for method training and transfer could be identified. They are divided into target group independent requirements, requirements towards design education and towards practice. Hence, the requirements are also divided for design education and practice.

An excerpt of the requirements list is presented in Table 5-2. It contains all above-derived requirements in the described structure (independent from the target group, practice and design education).

Table 5-2 Excerpt of the complete requirements list showing all requirements on method transfer and training

structure	no.	name
5. training and learning methods (in general)	5.1	low time effort for learning method
	5.2	pilot projects or/and usage of real design tasks
	5.3	training and provision of support
	5.4	involvement of designers in method selection
	5.5	provision of reflection and experience exchange possibilities
	5.6	offer training/action possibilities
	5.7	fast transparent benefits
	5.8	quick results and time saving through methods
	5.9	usage of realistic examples and exercises
	5.10	including reflection/feedback on methods and their application in training
	5.11	reflection includes benefits, results and time needed
	5.12	combining method access in method portal with training
	5.13	considering different types of learners and knowledge levels
5. training and learning methods for practice	5.14	consideration of organisation's needs
	5.15	planning of implementation
	5.16	interdisciplinary change teams
	5.17	top management support
	5.18	method champions (experts)
	5.19	identifying real tasks for method trainings prior to training
	5.20	identifying organisation's needs prior to training
	5.21	including workshop before and after training for top management, multidisciplinary change team and method expert to plan implementation
5. training and learning methods for design education	5.22	using projects or other types of teamwork for method application
	5.23	attraction and motivation through entertaining formats and media
	5.24	attraction and motivation through diversification of courses

5.4 Reflection on research question

As introduced at the end of chapter 4, this last section will be again used to conclude and reflect on the research question which was addressed in this chapter. The analysis revealed fruitful insights for answering the research question Q5 *"What are success factors and barriers for method knowledge transfer in design education and practice?"*

- This research question was already roughly addressed in the state of the art. In this chapter, an extensive analysis of success factors and barriers found in literature was conducted. The success factors and barriers to method knowledge training and transfer were considered for the target groups design education and practice.

- More than 50 success factors and barriers could be identified in literature. They were summarised in four clusters being presentation of methods, implementation and support, acceptance of methods and consideration of daily work.
- Beside success factors and barriers, formats and media and their potential for method knowledge transfer were analysed. A variety of formats and media is already used in design education. These formats and media are: documents, checklists, videos, method portals or (digital) method descriptions, mobile applications, games, virtual team workshops, workshops and training, and projects.
- In excess of the research question the answer was used to deduce requirements on suitable training concepts and formats. This can be seen as preparatory step for answering research question Q6 in chapter 7.

6 DEVELOPMENT OF A METHOD PROVISION TOOL FOR TEAMS

"It is common sense to take a method and try it.
If it fails, admit it frankly and try another.
But above all, try something."
Franklin D. Roosevelt, American president

If one design method fails due to certain reasons, the team should not resign but go for another method and try it again. To avoid frustrating events like this, the purpose of this chapter is to identify relevant influencing factors of the team on the method application. With the help of these factors, suitable methods can be chosen for a team or adapted in a way that they fit. So, the eventuality of failing with the method might be reduced.

To achieve the above-mentioned purpose, this chapter is divided into three sections (see Figure 6-1): the first part (Section 6.1) addresses research question Q3: *"How do method user characteristics influence the methods' application in engineering design?"* The section deals with the identification of possible team-oriented attributes for method provision. Therefore, a sensitivity analysis of the method user characteristics as well as further team-oriented attributes is conducted. The result and answer to Q3 is an impact model with relevant attributes for a team-oriented method provision.

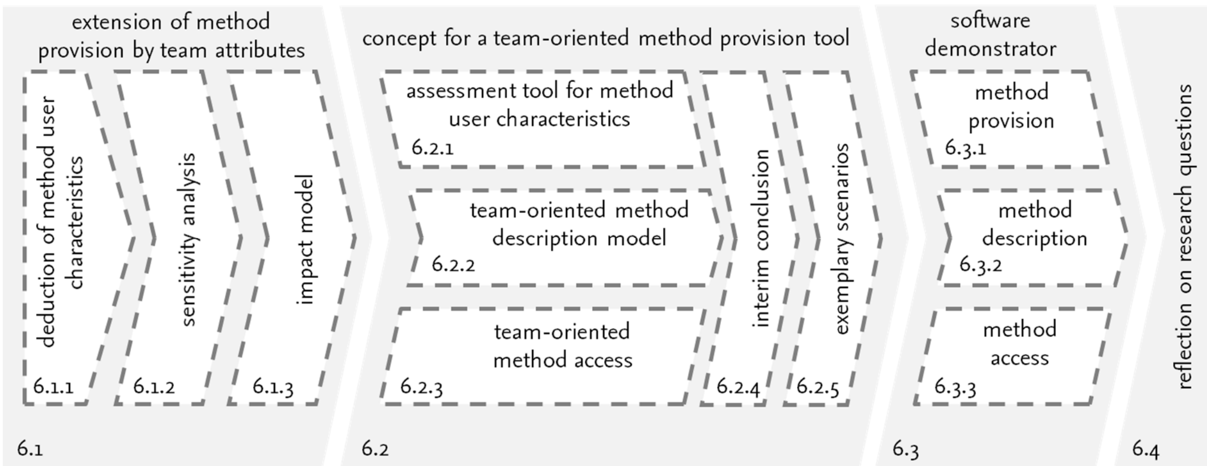


Figure 6-1 Schematic illustration of the chapter's structure

The second part (Section 6.2) will give an answer to research question Q4 *"How can method user characteristics be identified and considered in method provision and application?"*

by proposing a corresponding concept for a method provision tool for teams. This tool concept consists of an assessment tool concept for relevant method user characteristics, a team-oriented method description model and team-oriented access algorithm. The concept of the team-oriented method provision tool is demonstrated in exemplary design scenarios at the end of this section.

The third part (Section 6.3) presents a software demonstrator called METHODOS that includes most of the before decribed features of the concept for the method provision tool for teams. The aim is to provide a demonstrator that allows the realisation of the evaluation studies (see chapter 8) and not the provision of a complete and extensive tool. The chapter ends with a conclusion in Section 6.4.

6.1 Extension of current method provision approaches

To identify relevant team-oriented attributes for the method provision tool, potential characteristics of the method user respectively the team, that have already been described in the state of the art (see Section 2.2) are deduced in Section 6.1.1. Subsequently, the identified characteristics of a team are considered regarding their influence on the application of selected methods within a sensitivity analysis in Section 6.1.2. The resulting influencing characteristics are gathered in an impact model as a conclusion of this section and to give an answer to Q3 (Section 6.1.3).

6.1.1 Deduction of method user characteristics for method provision

The extension of current method approaches by team-oriented attributes is based on method user characteristics, which are clustered in team characteristics (like *hierarchical differences* and *roles in a team*), competencies (like *professional* and *social competence*) as well as collaboration characteristics (like *local* and *temporal distribution*). The starting point are the attributes that were earlier proposed in literature and that are already part of the analysis in chapter 4 (see black dots in Figure 6-2). As most of the literature in the field of engineering design and literature on teams have no direct method context, the corresponding authors used in the following section are added to Figure 4-27 to give a more complete overview on the relation of method and method user / team. The newly added literature on teams is represented by grey dots (mainly assigned to one topic on the ordinate) or grey ovals (assigned to multiple topcis on the ordinate) in Figure 6-2.

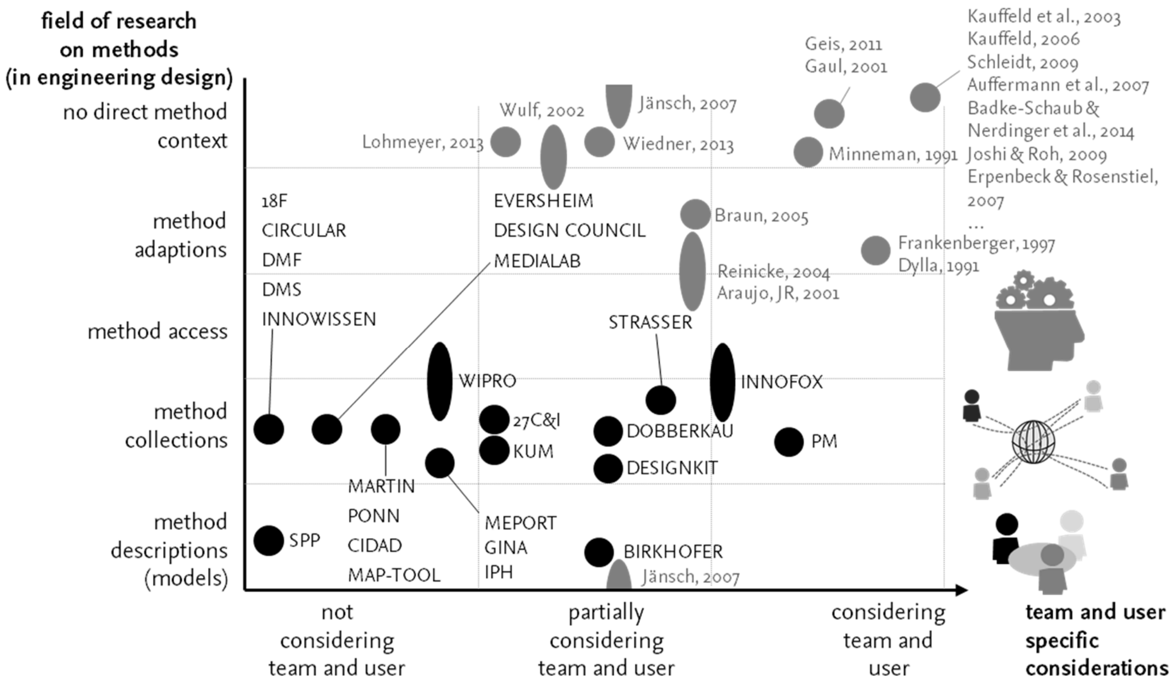


Figure 6-2 Extension of Figure 4-27 with literature regarding (design) teams: black dots/ovals originate chapter 4, grey dots/ovals are added in this chapter; ovals are assigned to multiple topics on the ordinate

The following paragraphs gather potential team-oriented attributes for a method provision tool according to the three categories of method user characteristics.

Team characteristics

As some team-related or method user-related attributes were already identified within the analysis of existing method collections in chapter 4, these attributes are considered here as well. These attributes are:

- *team size* (considered by DOBBERKAU, STRASSER, 27C&I, INNOFOX and PM),
- *roles within the team* (considered by DOBBERKAU, STRASSER, INNOFOX and PM; mentioned by Geis (2011)),
- *qualification of the team* (proposed by BIRKHOFER and considered in DESIGNKIT and PM), and
- *experience with method usage* (proposed by BIRKHOFER and considered by KUM, DESIGNKIT, INNOFOX and PM).

These already considered attributes are marked with an asterisk (*) in Figure 6-3, which summarizes all team characteristics used for the sensitivity analysis later on.

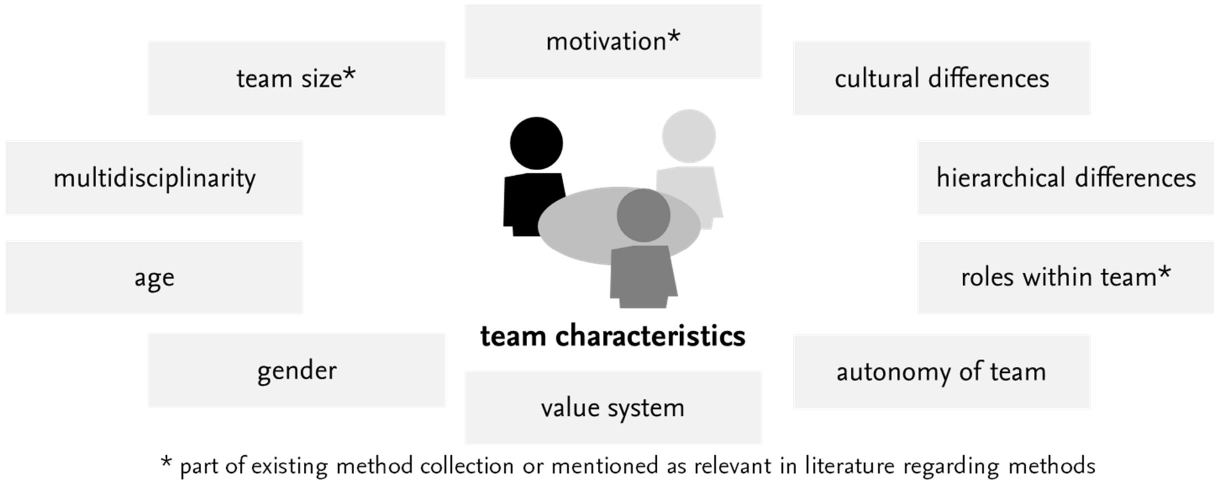


Figure 6-3 Team characteristics derived from literature on (design) teams

Another author dealing with design methods and their application (Ponn, 2007) also mentions the *motivation*, *abstraction ability* (in the sense of abstract thinking on systems) and *communication skills in team* as important factors for engineering designers. Though, in the corresponding method descriptions of Ponn (2007), these attributes are not considered. The *abstraction ability* and *communication skills in team* belong more to the superior term of competencies rather than to the term team characteristics. Thus, they are assigned in the next section on competencies to the four competence facets. The *motivation*, however, will be included in the sensitivity analysis. Another author presents an overview of extrinsic and intrinsic influences on method application (Braun, 2005). He names mainly Dylla (1991) and Frankenberger (1997) as references for human-related influences. Besides the *motivation*, *experience, roles within the team* and *qualification*, they list *competencies*, *hierarchical position*, *value system*, *knowledge*, *emotions* and *capability* on the individual level. On the team level, *structure of team, cultural background, language* and *external support* are listed besides other already mentioned factors. These aspects will be considered in detail and clustered from literature on teams and teamwork in the following.

Focussing on literature dealing mainly with teams and teamwork, not necessarily in the context of engineering design and method application, diversity is one of the major aspects. Joshi and Roh (2009) list their results of a literature review on studies dealing with diversity aspects. The aspects most mentioned are age, gender, race, function/position, education and experience. This matches mostly the aspects of diversity clustered by

Nerdinger et al. (2014) in demographical characteristics (age, gender, cultural background and education), know-how and experience, personality, value system and social status. For the sensitivity analysis, *age* and *gender* are directly taken into the set of team characteristics. Race and cultural background are combined to *cultural differences* in a team. Educational aspects as well as experiences will be considered within the competencies, as there is a competence-based approach instead of a qualification-based chosen in this thesis. The idea is that for the method application the competencies enabling the owner to cope with certain situations are more relevant than qualifications, which are accredited to the owner (according to Erpenbeck and von Rosenstiel (2007) or Kauffeld and Paulsen (2018)). Thus, *qualifications* (as proposed by BIRKHOFER and considered in DESIGNKIT and PM) and experiences, especially *experience with method usage* (proposed by BIRKHOFER and considered by KUM, DESIGNKIT, INNOFOX and PM) are considered among the competencies (see paragraph *competencies*).

The function, respectively the position, will be considered as *hierarchical differences* to enable a suitable evaluation within the sensitivity analysis referring to no respectively low differences in the hierarchy up to high differences. In addition, the aspect of diverse disciplines or knowledge domains will be considered. Lohmeyer (2014) mentions that designers have to cope with the "social-technical challenge" referring to interdiscipilinary contexts. Thus, the *multidisciplinarity* shall be considered in the sensitivity analysis as well.

Another aspect widely discussed in design context is the *value system*. Araujo, JR (2001) discusses the importance of beliefs, attitudes and behaviours towards methods. Coming back to the clusters of Nerdinger et al. (2014), these aspects are considered under the term *value system*.

As described in chapter 2 regarding teams and the management of teams, there has been a shift from behaviour-oriented management of teams towards a result-oriented management. Result-oriented means a higher self-direction of the team, thus, a higher *autonomy of the team* (Kauffeld, 2006b). It is assumed that the *autonomy of the team* also has an influence on the method application.

Competencies

There are various definitions of competencies among the scholars (Kauffeld, 2006). Badke-Schaub and Frankenberger (2004) used the four competence facets *professional*, *social*, *methodological* and *self-competence*, e.g. Kauffeld (2006b), Kauffeld et al. (2007), in their research and state recommended actions in critical situations based on these four facets. The advantage of this competence model is that the *professional competence* is seen as the main part. *Social*, *methodological* and *self-competence* are needed for support to bring out the *professional competence* of a person (Kauffeld, 2006a).

Further aspects of competences were found in literature (see chapter 4) like the *qualification of the team*, *abstraction ability*, *communication skills within the tea*m and *experience with method usage*. These aspects are assigned according to descriptions of the competence facets in Kauffeld et al. (2007) as well as in Badke-Schaub and Frankenberger (2004) to the four competence facets as shown in Figure 6-4. *Qualification* and *abstraction ability* focussing on abstract systems as a core competence for designers belong to the *professional competence*. *Communication skills within the team* are assigned to the *social competence*. One element of *methodological competence* is the *experience with method usage* in general, which also Braun (2005), Araujo, JR (2001) and Lutters et al. (2014) emphasise as important regarding method acquisition respectively application. Due to this importance, it is considered apart from the *methodological competence* in the analysis, although it belongs to this competence facet (light grey colour in Figure 6-4).

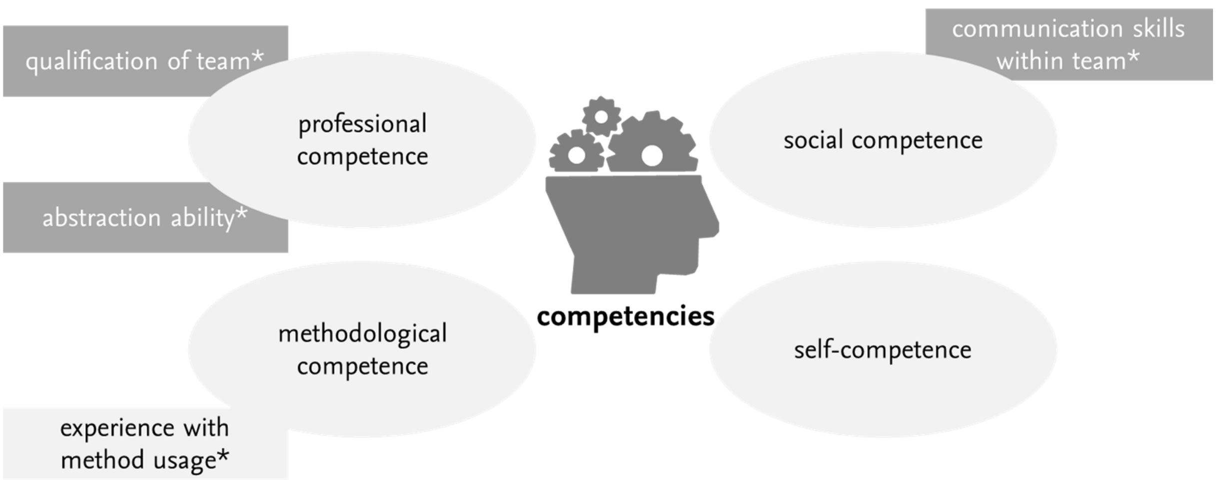


Figure 6-4 Competencies of individuals and teams found in existing method collection or literature (marked with *) regroupped under the four competence facets (oval boxes)

Nieberding (2010) refers additionally to design capability (from Günther (1998)) and the level of maturity of a design team (from Ehrlenspiel and Dylla (2007)). Both aspects describe special competencies and abilities of designers to successful master a design task. Thus, these aspects can mainly be seen as part of *professional competencies* and *methodological competencies*.

Especially for collaborations and virtual teams, some authors propose further competencies, e.g. Auffermann et al. (2007) or Schleidt (2009). These competencies are amongst others creativity competence, cooperation competence, intercultural competence or work-life-balance competence, see (Schleidt, 2009). For a correlation with the application of single methods, these competencies go into too much detail to gain reasonable conclusions. Thus, only the four superior competence facets are used for the sensitivity analysis.

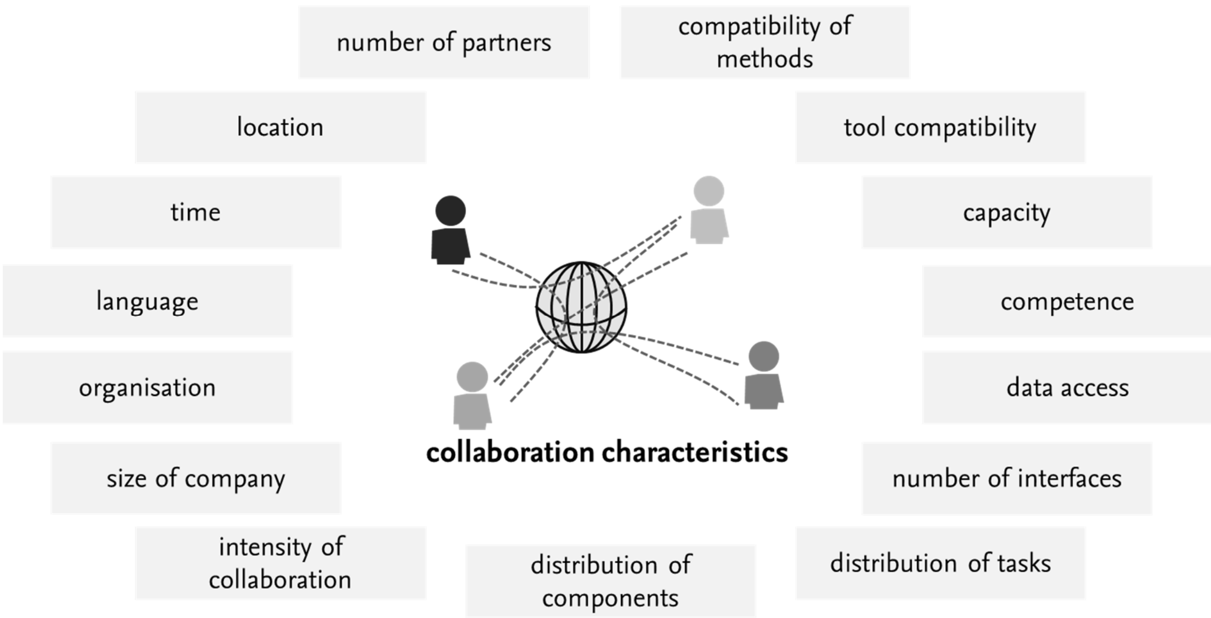


Figure 6-5 Collaboration characteristics from literature according to (Gaul, 2001)

Collaboration characteristics

Regarding virtual teams and collaborations in general Gaul (2001) proposed a list of 15 so-called collaboration characteristics (see Figure 6-5 and Section 2.2.2.2). There are further authors characterising collaboration situations like Schleidt (2009). Schleidt (2009) uses dimensions of collaboration including time zones, interactions and communication as well as diversity. All of the dimensions can be found in the more extensive list of Gaul's collaboration characteristics. The latter are more suitable for a correlation with method usage as each characteristic only focuses one aspect. This allows a better evaluation of the correlation.

In conclusion, 30 characteristics of a team have been identified in literature and from existing method collections and models. These will be investigated regarding the influence on the method application in the following.

6.1.2 Sensitivity analysis of relevant team-oriented attributes

The sensitivity analysis has the aim to identify those team-oriented attributes that are worth the consideration within method descriptions and method access. This means that the change of the attributes' values has an impact on the method application. A simple example is the change of the *team size* from two team members to six members for a Brainstorming. The bigger team will probably come up with more different ideas than the smaller team.

Scale

To estimate the importance of this influence, a 5-point scale as shown in Table 6-1 is used. The meaning of each point on the scale regarding the method application is indicated in the right column.

Table 6-1 Scale for the sensitivity analysis

symbol	value (for summing up)	meaning regarding the method application
	1	no influence
	2	low influence
	3	medium influence
	4	high influence
	5	very high influence

An example again using the *team size* is the Method 635, which should be applied with six persons. It is still applicable with some persons more or less but it becomes useless if only one person applies the method. Even two or three persons lead to probably less diverse results. The influence of the *team size* is similar to further creativity methods but it is the only method rated this high for the attribute *team size*. The reason is the in general missing predetermined number of team members for other creativity methods. Medium influences for this characteristic of the team are evaluation methods, for which more team members can have a positive impact on the result. But in general an evaluation can also be made by a single person, whereas a creativity method with one person is not productive.

Methods for the sensitivity analysis

To reduce the complexity of the sensitivity analysis, the methods considered in the analysis are limited to fourteen exemplary methods. The methods are chosen from different method classes aiming at the support of varying activities in the design process: methods for analysis and aims, for solution generation, for evaluation and decision-making and one general method. These methods shall represent the diversity of engineering design methods, thus, they also have different levels of difficulty and complexity.

Realisation of the sensitivity analysis

The methods grouped in the above-mentioned method classes are the content of the columns in Table 6-2 whereas the method user characteristics appear in the rows. The latter are clustered in the three categories introduced in Section 6.1.1. The last column of the table contains the average of the influence of each characteristic as a number. The complete table with remarks on the evaluation, references and examples is part of Appendix C1.

The rating of each influence was conducted within an expert team consisting of psychologists holding a master's degree or PhD in work and industrial psychology from the Department of Industrial/Organizational and Social Psychology (TU Braunschweig) with expertise on competencies, teamwork and interdisplinary projects and engineers and engineering students holding a master's or a bachelor's degree from the Institute for Engineering Design (TU Braunschweig) with expertise in the field of systematic design and design methods.

The characteristics rated in average higher or equal to 3.0 over all methods are highlighted in grey in Table 6-2. These aspects are considered relevant and will be used in the following.

Table 6-2 Results of the sensitivity analysis (highlighted in grey are characteristics with more than Ø 3.0)

method classification
methods for analysis and aims
methods for solution generation
methods for evaluation and decision making
general methods

method user characteristics		discussion in a group	benchmark	documentation of requirements	persona	literature and patent research	QFD	brainstorming	gallery method	method 635 (brainwriting)	synectics	Morphological Analysis	cost utility analysis	FMEA	point rating system	Ø
		sensitivity regarding methods														Ø
team characteristics	team size*															3,4
	multidisciplinarity															3,6
	hierarchical differences															3,1
	age	?														0,0
	gender															2,3
	cultural differences															3,1
	roles within team*															2,9
	value system		?	?		?			?	?		?	?	?	?	2,6
	motivation*															3,5
	autonomy of team															1,9
competencies	professional competence (abstraction ability*, qualification*)															4,0
	social competence (communication skills within team*)															3,0
	methodological competence															3,1
	self competence															3,1
	experience with method usage*															3,1
collaboration characteristics	number of partners	see team size														0,0
	location															3,4
	time															3,4
	language															3,6
	organisation															2,4
	size of company															2,7
	intensity of collaboration															2,3
	distribution of components															1,6
	distribution of tasks															1,1
	number of interfaces															2,5
	data access															2,4
	competence	see more detailed competencies														0,0
	capacity															2,5
	tool compatibility															2,1
	compatibility of methods	?														0,0

6.1.3 Impact model and resulting requirements on method provision

The result of the sensitivity analysis is an impact model representing all relevant characteristics of a team that were considered as important (higher or equal to 3.0 on a scale from »1« to »5« points) during the analysis. The model is shown in Figure 6-6. The different nuances of grey combined with the symbols demonstrate the original category of the final characteristics within the model. The average influence over all methods considered appears on the right side of each box.

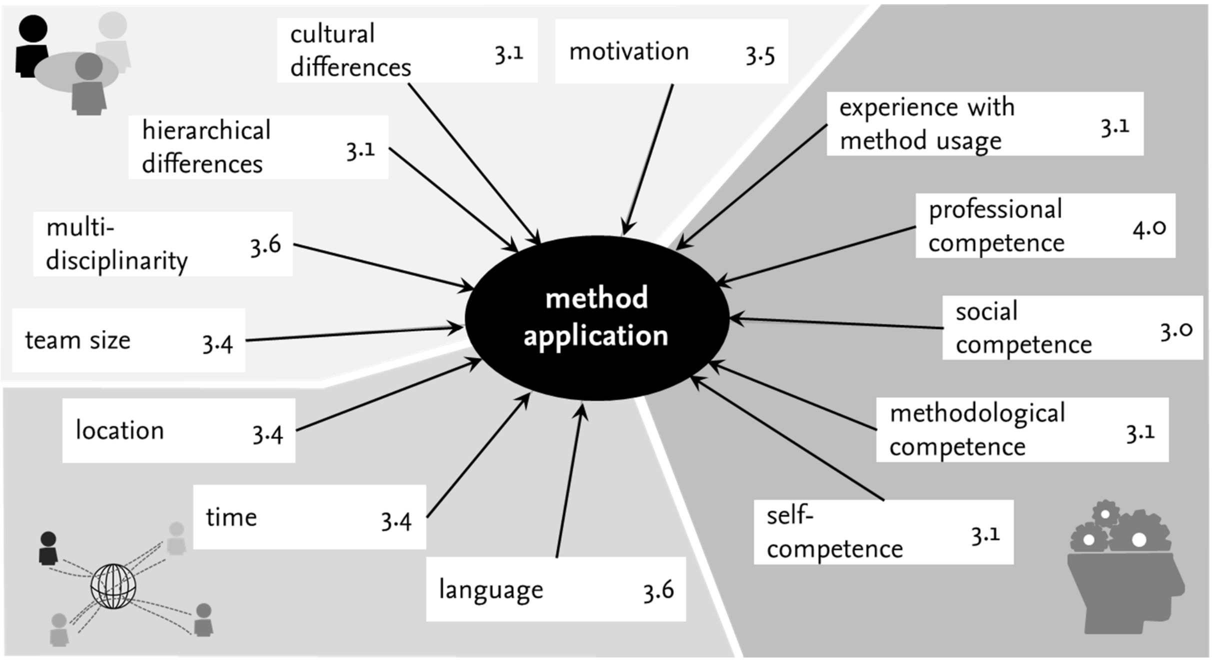


Figure 6-6 Impact model of the resulting characteristics from the sensitivity analysis

The impact model, as it appears here, tries to answer research question Q3 "*How do method user characteristics influence the methods' application in engineering design?*" These characteristics can be used as attributes for a team-oriented method provision. The final selection of the attributes for the newly developed method provision tool for teams will be done in Section 6.2.1.

Requirements on a team-oriented method provision

Beside the requirements on a method provision tool derived beforehand these influencing attributes on the method application demand further requirements: Due to the possible virtual or locally distributed application of methods, the method provision has to be digitally available. An online version or application seems the best solution to grant access for all team members. In addition, the local distribution limits the applicability of some of the methods. So, the provision of hints for virtual teams on how to adapt methods for these teams is necessary. If there are also team members with different languages involved, multilingualism is required. The comprehensibility also plays an important role, especially when the descriptions of methods are provided in different languages. The quality of the description and important terms have to be consistent.

To summarize the findings from this section, the method user characteristics identified as relevant on the method application are added to requirement no. 3.5 as values from the intitial requirement list of Section 4.4.3. Additionally, the requirements derived above complete the requirements list, which can be found in Appendix A5 in the final version. The final requirements list serves as basis for the development of the concept for a team-oriented method provision tool.

6.2 Concept for a method provision tool for teams

This sections aims at the development of a concept for the team-oriented method provision tool. The basis is provided by the requirements formulated in the previous chapters and sections to generate a suitable solution. The greater goal is to find an answer to research question Q4: *"How can method user characteristics be identified and considered in method provision and application?"* The question can be divided into two aspects: (1) the identification of relevant characteristics defined in the impact model (see Section 6.1.3) of the underlying method user or team and (2) the consideration of these characteristics in method provision. The latter will be separated into method description and method access according to the analysis in chapter 4. Thus, this section is structured in three parts as illustrated in Figure 6-7. The figure presents the general goal, the concept of a team-oriented method provision tool: It is built on the left-hand side from an assessment tool (see Section 6.2.1) to identify the method user characteristics (part (1) of Q4). On the right-hand side, it is built from method description (see Section 6.2.2) and method access (see Section 6.2.3) forming an answer to part (2) of Q4. The idea is to use standardized team-oriented attributes for the method description and the team profile to enable a direct method access via these attributes, symbolized by the arrows in Figure 6-7.

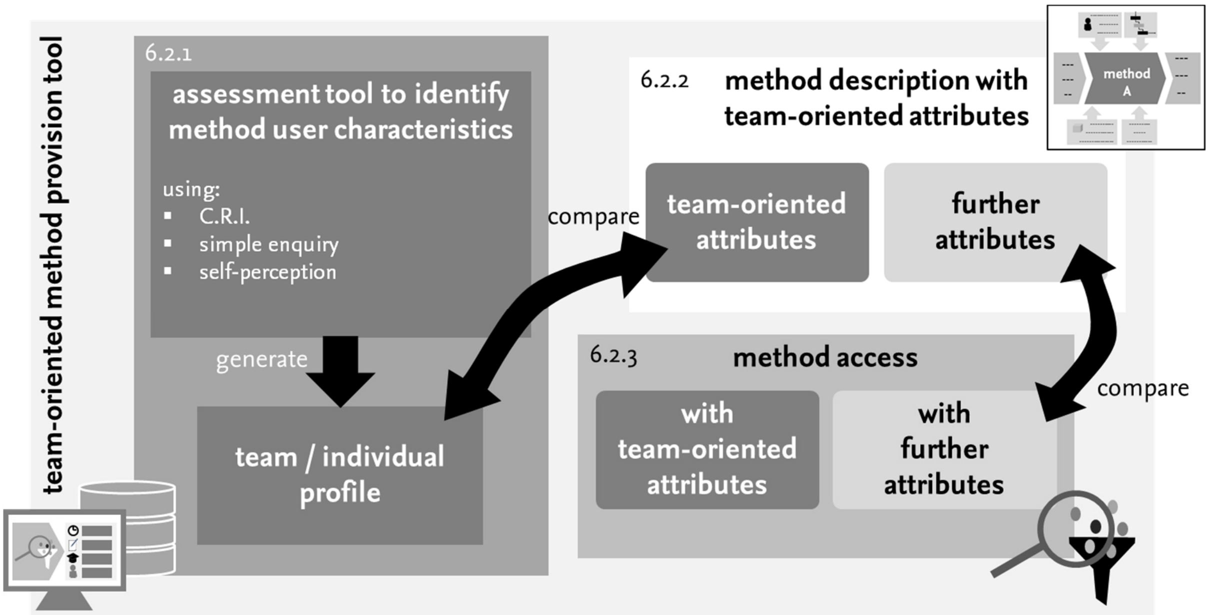


Figure 6-7 Overview of the elements of the concept for the method provision tool for teams

6.2.1 An assessment tool for determining method user characteristics

The first element of the method provision tool for teams is not directly connected to engineering design methods. This section deals with the development of a concept for a so-called "assessment" tool, which is used to identify the characteristics of an engineering design team to build a profile. The profile is then used to match the methods to the team or vice versa (see Section 6.2.5). The name "assessment tool" is used as an umbrella term for all kinds of assessment tools such as aptitude or screening tests. In this thesis, an assessment tool means a tool to gather information on the individual and on the team to identify method user characteristics that are used for the team-oriented method provision. It will not be a complete assessment tool or instrument like they are developed in the domain of psychology; typical quality criteria like validity, objectivity and reliability will not be considered. In fact, mainly self-perception of one individual or the team as well as simple enquiry will be used to estimate the predefined values for an attribute for the team. The difference between self-perception and simple enquiry is that the last-mentioned questions can be answered objectively whereas for self-perception a subjective estimation of one of the team members is required. For more complex assessments, an established and validated instrument from psychology like the "Competence-Reflection-Inventory" will be applied. The assessment tool is designed for individuals or engineering design teams that wish to use a method for their task. Thus, the tool has to be applicable for individuals and for teams as well. As a further requirement towards the tool it is rather important that it is easy and fast to apply without unnecessary questions; only the team-oriented attributes are relevant as deduced in the impact model.

Motivation is the only attribute which is not considered for the team assessment due to the following reasons: The *motivation* (suggested by Ponn (2007)) of a team for fulfilling a task or applying a method is always preferably high. A low *motivation* can have a negative influence on the method result, anyway. Thus, it is important to establish a high *motivation* beforehand, a willingness to change and the acceptance for a method (Jänsch, 2007). As this refers to all methods, this team characteristic will not be used to describe or access methods although it is extremely relevant for the successful method application.

Table 6-3 Team-oriented attributes with values and way of data collection

method user characteristics		values	way of data collection
team characteristics	team size	1; 2-3; 4-6; 7 and more	simple enquiry
	multidisciplinarity	heterogeneous; balanced; homogeneous	self-perception
	hierarchical differences	yes; no	simple enquiry
	cultural differences	same culture; similar culture; different culture	self-perception
competencies	professional competence	below Ø; below Ø to Ø; Ø; Ø to above Ø; above Ø	C.R.I.
	social competence	below Ø; below Ø to Ø; Ø; Ø to above Ø; above Ø	C.R.I.
	methodological competence	below Ø; below Ø to Ø; Ø; Ø to above Ø; above Ø	C.R.I.
	self competence	below Ø; below Ø to Ø; Ø; Ø to above Ø; above Ø	C.R.I.
	experience with method usage	beginner; advanced; expert	self-perception
collaboration characteristics	location	distributed rooms; distributed locations; distributed countries	simple enquiry
	time	parallel; sequential; mixed	simple enquiry
	language	same language; different language; one common language	simple enquiry

Table 6-3 gives an overview of the further attributes considered relevant in the previous section. It also contains the values corresponding to the attributes and the way in which the information on the team shall be gathered. The next paragraphs are used to deduce the way of information gathering for each attribute and the used values for each of them.

Team size: 1, 2-3, 4-6, 7 and more

There exist various different suggestions how to define the *team size* for method descriptions. For example, some authors like 27C&I or PM only use individual and group as differentiation. Other authors list precise numbers of team members for the methods, e.g. INNOFOX. In this thesis, the focus is on the team, thus, the more precise variant with numbers of team members is preferred. For the gradation, it is important to have the »1« as definition for an individual and »7 and more« for bigger teams or groups having in general a fewer teamwork quality (Hoegl, 2005). In between, one further gradation is made differing between »2-3« and »4-6«. The reason is the theoretically best team size of 3 to 6 persons for tasks performance (Hoegl, 2005) and the consideration that 2 to 3 persons can be good for methods normally being applied individually to enhance the quality of the results, e.g. evaluation or systematic methods. This characteristic of the team is asked as a simple enquiry.

Multidisciplinarity: heterogeneous, balanced, homogeneous

Multidisciplinarity is only one aspect of diversity. Experts from diverse fields can contribute different knowledge, e.g. for ideation or for evaluation of solutions. As the department or the position are not always clearly named and the persons do not have obligatory expertise in the domain, which they are officially assigned to, the multidisciplinarity is asked by a self-perception of the team. In this way, the team members can rate on how diverse they feel in disciplines (as knowledge on the collaboration, e.g. Brandstädter and Sonntag (2016)). The gradation is from »heterogeneous«, »balanced« to »homogeneous«. »Balanced« can mean, e.g. two disciplinies involved, which are quite close like two engineering disciplines.

Hierarchical differences: yes, no

Due to the influences on the team dynamic of *hierarchical differences* in means of the power distance dimension (Hofstede, 1983), this attribute is considered with a simple enquiry answered with »yes« or »no«. If the hierarchy is not obvious, the answer has to be self-perceived by the team or one member.

Cultural differences: same, similar and different culture

When talking about distributed working teams, *cultural differences* play mostly an important role due to team members originating from different countries and cultural backgrounds. The term “culture”, also often referred to as “race” or “ethnicity”, is widely discussed and there are various understandings, e.g. Hall (1976), Hofstede (1983), Huntington (1993), and examinations regarding teams. For an overview see Joshi and Roh (2009). As the primary focus is not on this aspect, basic considerations with a gradation of »same«, »similar« and »different culture« are chosen. The idea is based on the cultural understanding of Hofstede et al. (2010). The determination is made by a self-perception. In this way, the team members can estimate their own understanding of *cultural differences*.

Professional competence: below Ø, below Ø to Ø, Ø, Ø to above Ø, above Ø

Some authors like PM include an attribute called qualification. This implies qualifications in different fields like being a good moderator or having experience with scheduling of projects. As explained in Section 6.1.1, a competence-based approach for the team is chosen. Qualification belongs, thus, to *professional competence*. It has to be kept in mind that for certain tasks, like decisions, technical approvals, etc., special qualifications might be necessary, but without further competence they are in general not sufficient. Thus, an additional competence enabling the qualified person to apply their knowledge is required.

As competencies are situation or task related (Kauffeld, 2006a), process analytical techniques to observe the design team in a typical situation would be a promising technique to determine the four competence facets (*professional, social, methodological* and *self competence*) for the team profile. ACT4TEAMS (Kauffeld & Lehmann-Willenbrock, 2012) is a possible tool for this kind of process analytical technique. Due to the time and personal resource consuming technique, in this approach a structure analytical technique is preferred. The “Competence-Reflection-Inventory”, short C.R.I., (Kauffeld & Henschel, 2010) is used to determine the four competence facets (*professional, social, methodological and self-competence*) for the team profile. Each team member applies the test. As categories for the assessment tool, the categories »below Ø«, »below Ø to Ø«, »Ø«, »Ø to above Ø«, and »above Ø« are suitable, e.g. Westhoff and Kluck (2008). Therefore, the eleven-point scale from »0« to »10« has to be converted according Westhoff and Kluck (2008). To do so, the available data of two samples consisting of n=561 in total presented by Henschel (2005) were used: The mean (M) plus/minus the standard deviation (SD) is used for the upper and lower value. The corresponding confidence interval (CI) on a confidence level of 95 % of the mean helps to define the gradation in between. The resulting values for the *professional competence* are as follows:

- <55: below Ø
- 55-70: below Ø to Ø
- 71-75: Ø
- 76-91: Ø to above Ø
- >91: above Ø

The values and calculation for all four competence facets can be found in Appendix C2. For defining the value in the team profile, an average of the individuals' values is taken for each facet.

Social competence: below Ø, below Ø to Ø, Ø, Ø to above Ø, above Ø

The *social competence* is determined as the *professional competence* with the help of the corresponding facet of the "Competence-Reflection-Inventory". The converted values as described for the *professional competence* are as follows:

- <51: below Ø
- 51-68: below Ø to Ø
- 69-73: Ø
- 74-90: Ø to above Ø
- >90: above Ø

Methodological competence: below Ø, below Ø to Ø, Ø, Ø to above Ø, above Ø

The *methodological competence* is determined as the *professional competence* with the help of the corresponding facet of the "Competence-Reflection-Inventory". The converted values as described for the *professional competence* are as follows:

- <50: below Ø
- 50-68: below Ø to Ø
- 69-73: Ø
- 74-91: Ø to above Ø
- >91: above Ø

Self-competence: below Ø, below Ø to Ø, Ø, Ø to above Ø, above Ø

The *self-competence* is determined as the *professional competence* with the help of the corresponding facet of the "Competence-Reflection-Inventory". The converted values as described for the *professional competence* are as follows:

- <55: below Ø
- 55-71: below Ø to Ø
- 72-76: Ø
- 77-93: Ø to above Ø
- >93: above Ø

Experience with method usage: beginner, advanced, expert

Some authors of the analysed method collections like INNOFOX, BIRKHOFER and DESIGNKIT already use the attribute *experience with method usage*. Braun (2005) proposes to distinguish between method »beginner«, »advanced« method user and method »expert« when suggesting different approaches for introducing methods for product planning. These three levels of experience are chosen for a self-perception within the team profile for the method provision tool. The idea is to map the experience level of the method user to the degree of difficulty of a method. Thus, a simple method is suitable for all levels of experience, whereas a low experience level excludes methods that are more complicated.

Location: distributed rooms, distributed locations, distributed countries

The distribution of locations of the team members can be asked by a simple enquiry. The three gradations »distributed rooms«, »locations« and »countries« are directly taken from Gaul (2001). The gradation »distributed rooms« is used for no locally distributed collaborations where a face-to-face meeting is easy to arrange.

Time: parallel, sequential, mixed

The *time* and its values are directly taken from Gaul (2001). Here, a simple enquiry is used.

Language: same language, different language, one common language

Considering the *languages* spoken in the team, the values proposed by Gaul (2001) are adapted. As a gradation in between »same« and »different language«, the value »one common language« is introduced. The reason for chosing another level is to be able to differ between same mother tongue and one common language that all team members understand. However, not all of the team members might feel as free in this common language as they do in their mother tongue. For creativity methods, this might imply some limitations. The way of getting this information is a simple enquiry of each team member.

The result of the team's assessment before deciding on a method is the team profile. The team profile can be used for a comparison with the method descriptions to select matching methods for the team. An example of such a profile build from the above-deduced attributes is presented in Figure 6-8.

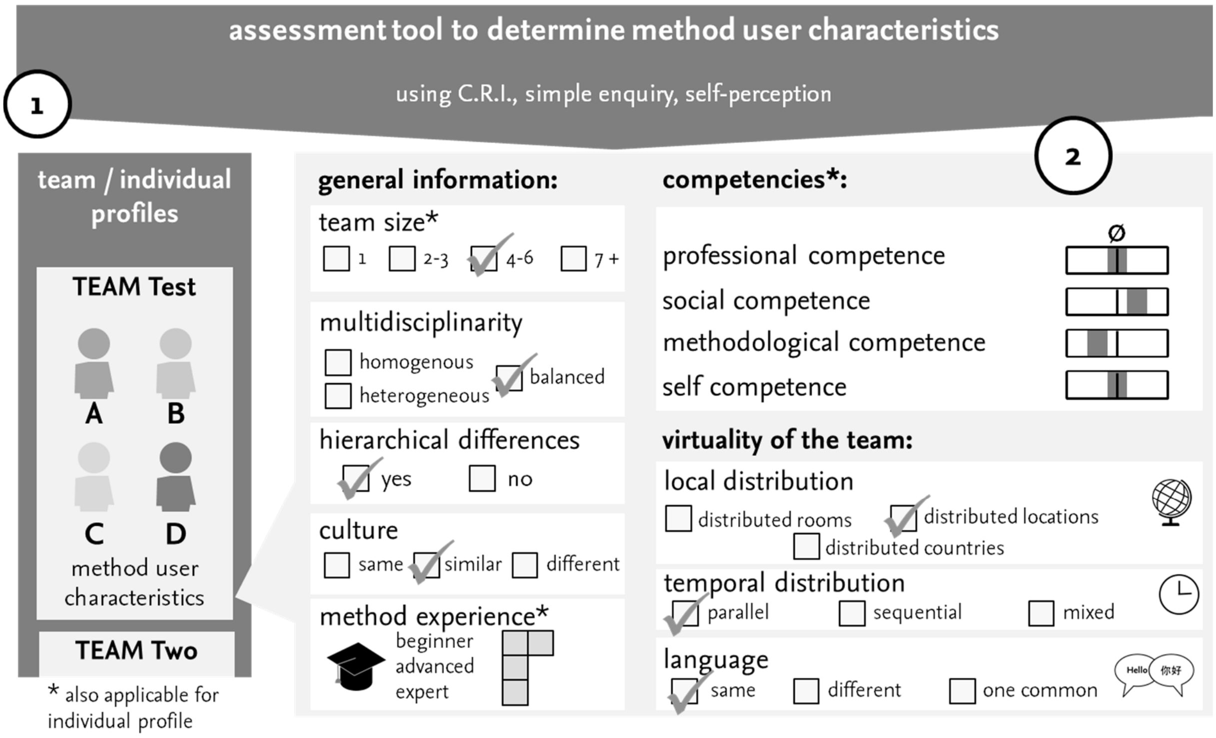


Figure 6-8 Using the assessment tool (1) to fill the team profile (2) presented at an exemplary team

The method user characteristics are clustered in groups (general information, competencies and virtuality of the team). Due to an easier understanding for the user of the profile, some attributes are named differently: *Cultural differences* are shortened to *culture*; *experience with method usage* is only called *method experience*; *time* and *location* are changed to *local* and *temporal distribution*.

Having described how to assess the prior defined team-oriented attributes and how to map them to a team respectively an individual profile for a method application, part (1) of research question Q4 is answered. In the following, it is described how these team-oriented attributes can be considered in method descriptions.

6.2.2 A team-oriented method description model

To answer part (2) of research question Q4, the identified method user characteristics have to be part of method descriptions and part of the accessing attributes within the method access. To answer the question generally, not limited to one example, a team-oriented method description model is developed based on the requirements list set up in the course of this thesis. To do so, first, the existing method collections and models are examined regarding good examples to build on. The paper-based method model PoMM of BIRKHOFER contains a great number of attributes while still being compact. Therefore, it is appropriate to build the basis for the team-oriented method description model similar to the approach of Saucken et al. (2015) extending the PoMM for Open Innovation methods.

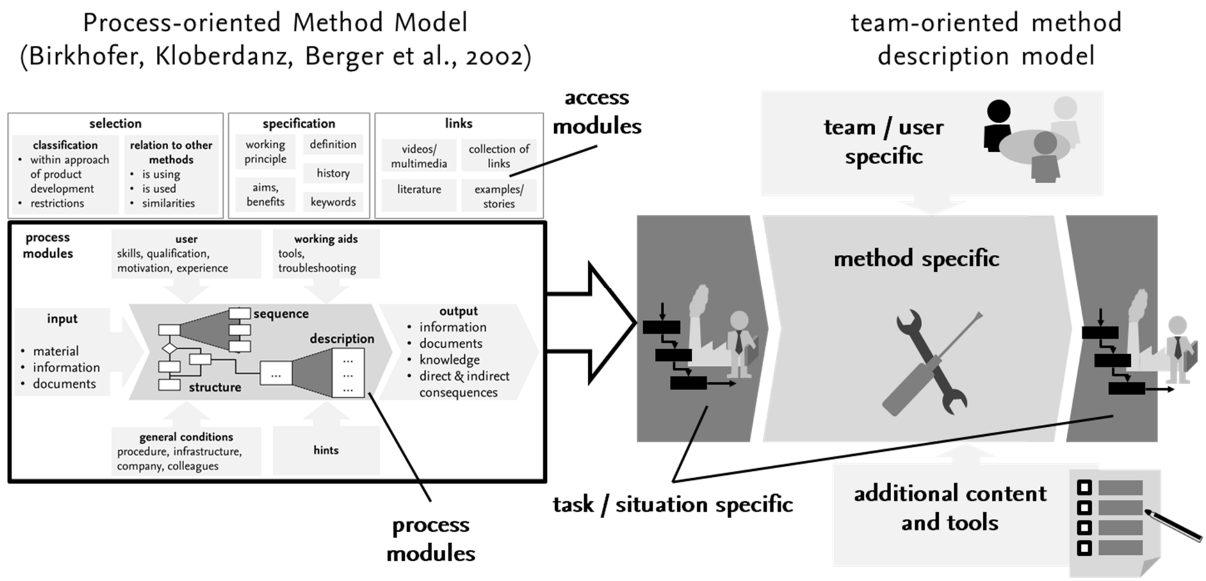


Figure 6-9 Process modules of the Process-oriented Method Model (Birkhofer, Kloberdanz, Berger et al., 2002) as basis for the team-oriented method description model

In this work, only the process modules (inner part of the PoMM) are used, see Figure 6-9. The outer access modules are not used, because the method access is considered separately in Section 6.2.3. The attribute clusters, formed during the analysis in chapter 4, are utilized to arrange the single attributes in reasonable groups. According to Birkhofer (2002), the method user / team has their own cluster located on the top of the model. The later part of this section will deal with this cluster in detail (see also Figure 6-11). Like in the model of Birkhofer, the method specific attributes are concentrated in the center of the model. They contain information on the procedure and a general description of the method. On either side of the central part, the task and situation specific attributes are located, e.g. inputs and outputs. The shape of arrows like in the PoMM is chosen to signalize the procedural character of a method. The "General Conditions" of Birkhofer's model are partly represented within the input arrow (situation specific) and the method specific attributes. Birkhofer's "Hints" and "Working Aids" are both part of the additional content and tools cluster, represented below the central part in the team-oriented method description model. Building on the PoMM allows fulfilling the first requirements on the team-oriented method provision tool, e.g. requirement no. 1.1 and 1.3 addressing the structured and uniform description as well as the clear layout and arrangement. The focus on the output is also given by the procedural character of the model (no. 1.6) and has to be preserved in a later online implementation. The further requirements towards the formalities refer to the usability and the quality of the method descriptions and can, thus, not be fulfilled by the description model itself but by the web-based tool when implemented online.

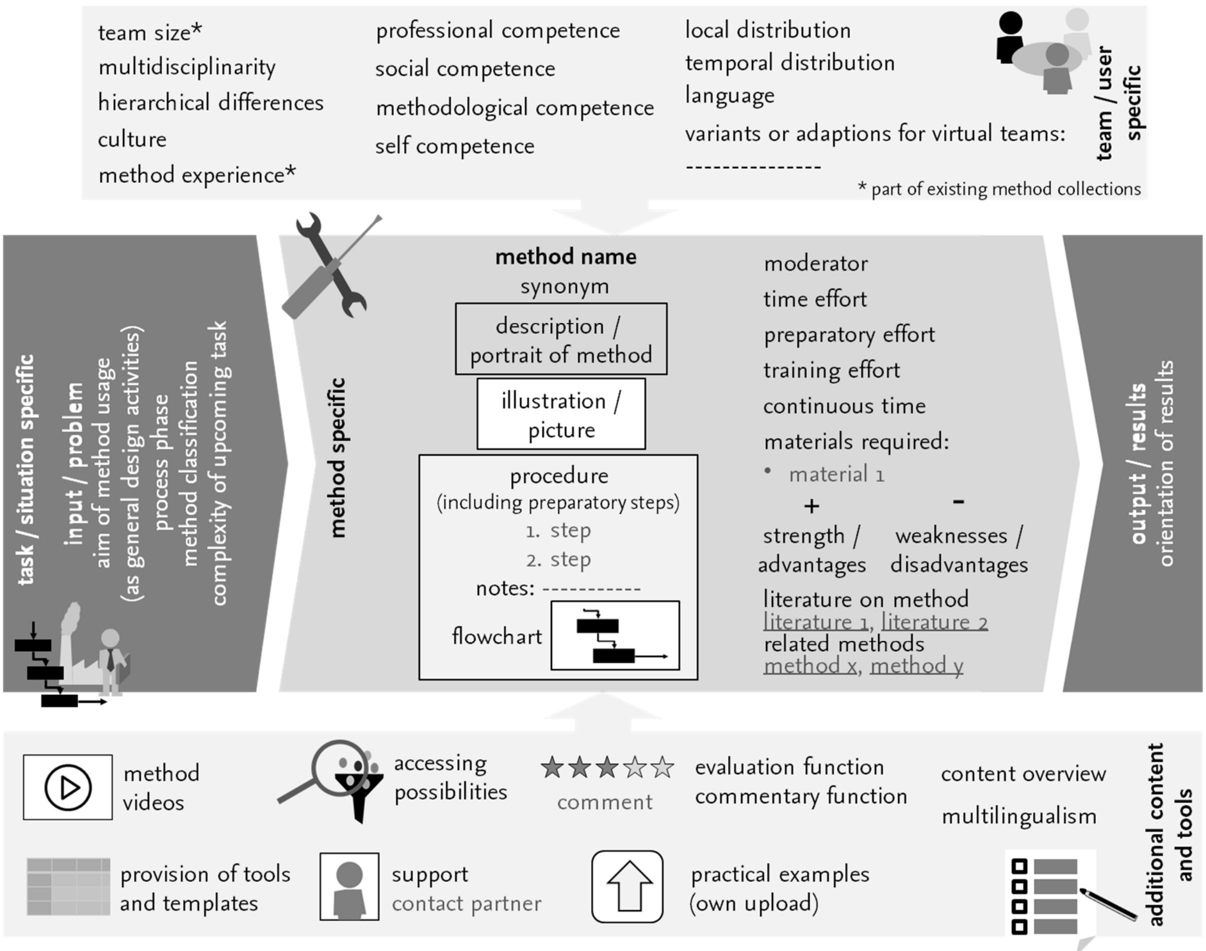


Figure 6-10 Detailed team-oriented method description model

Regarding the requirements on the contained attributes for each method description, the requirements no. 3.1 (considering method specific attributes) and no. 3.2 (considering task/ situation specific attributes) are fulfilled. The attributes are mainly a set of often used and important (referred to the MuPro-KMU survey) attributes. The attributes chosen are illustrated in Figure 6-10.

Considering practitioners' demands (no. 3.4) requires *tips for application*, *practical examples* and *tutorials/videos*. Tips are part of the procedural description in the method specific part of the model. *Practical examples* and *method videos* belong to the cluster of additional content and tools. Some of the requirements on additional content and tools of the team-oriented method provision tool are fulfilled within the method description model, like *providing templates and links* and *support*.

Figure 6-10 shows the complete team-oriented method description model and all contained attributes. The team and user specific attributes will be clarified in the following.

The remaining requirements no. 3.3 on the consideration of existing method and team / user specific attributes and no. 3.5 on the implementation of new team attributes, identified in the sensitivity analysis, are fulfilled in accordance to the team profile developed in Section 6.2.1. From existing collections and models, *team size* and *method experience* are adopted. The lasting ten attributes from the team profile *multidisciplinarity*, *hierarchical differences*, *culture*, the four competence facetes, *local* and *temporal distribution* as well as *language* are included as attributes in the team-oriented description model. An exemplary description of the method Brainstorming is presented in Figure 6-11. It contains the attributes with their values. The values marked with a check mark suit the method application without adaptions. Those values marked with an exclamation mark require adaptions of the original method application. These adaptions are another attribute called *variants or adaptions for virtual teams*. The aim is to provide usefull information in case of a local and or temporal distribution of the team. Possible hints for a method application in a virtual team could be tips for applying the method via video-conferencing or potential preparations like raising the awareness of cultural differences.

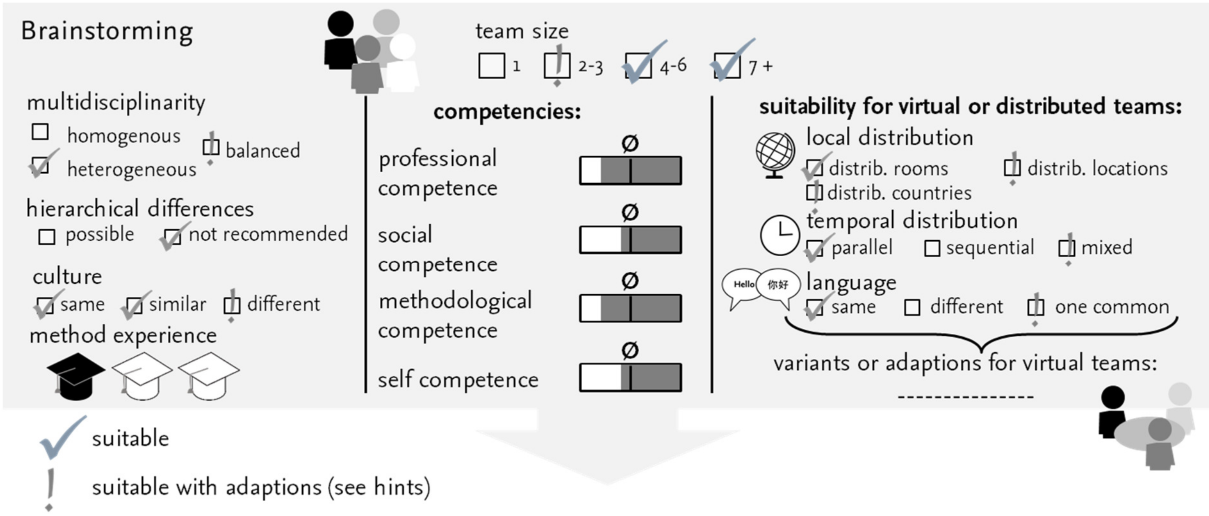


Figure 6-11 Detail view on team-oriented attributes for method descriptions

These team-oriented attributes together with the hints for adaptions and variants are exemplarily described for those methods considered in the sensitivity analysis in Section 6.1.2 as illustrated in Figure 6-12. The descriptions are part of Appendix C3. They were elaborated in accordance to the remarks of the evaluation within the sensitivity analysis. Each evaluation of an attribute contains a short description and hints for adaptions, if the original method is not applicable under the given value of the attribute. Further methods can be described for the team-oriented attributes with the help of the corresponding remarks in the sensitivity analysis.

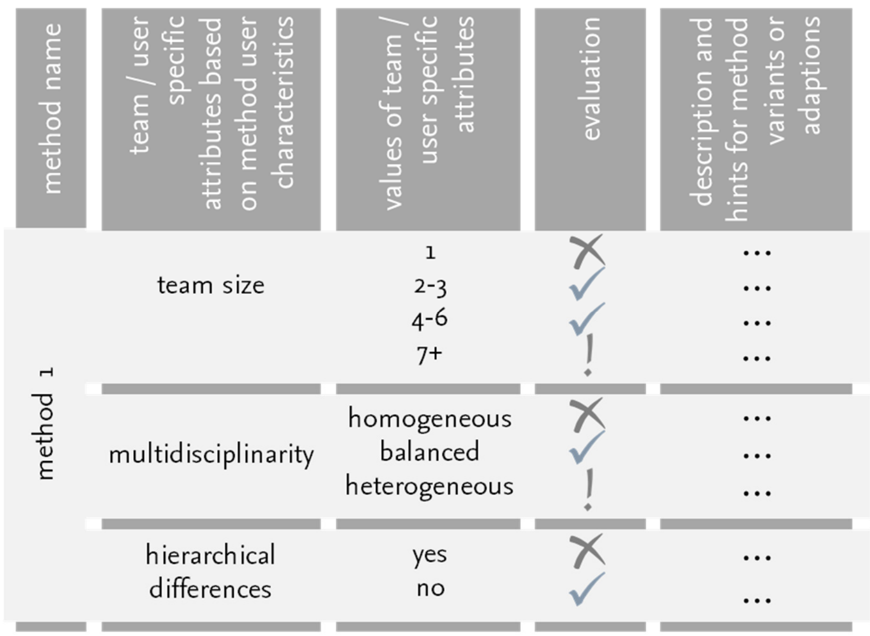


Figure 6-12 Schematic structure of team-oriented method descriptions including hints for variants and adaptions

Hence, the consideration of method user characteristics in a method description model as well as in exemplary method descriptions could be shown. This contributes to the answer of research question Q4, which will be fully answered in the next section.

6.2.3 A concept for method access considering method user characteristics

The second part of the team-oriented method provision is the consideration of a team-oriented method access. To develop this, first, the requirements on the method access from chapter 4 will be consulted. It will be defined which elements are required for a suitable access in general and with focus on the team or user. Thereby, formal access criteria, as well as access attributes, will be considered. Subsequently, an access algorithm will be presented demonstrating the usage of team / user specific attributes amongst other relevant attributes, e.g. *method aim*, for the selection of a suitable method. Finally, an exemplary query for a method search will be shown, detailing the team-oriented part of the method access.

Requirements on method access

The basic requirement for the method access is a web-based one. Thus, in the following, the concepts are thought to be an online tool and seem not always adequate for a paper-based presentation. Further requirements to be fulfilled are shown on the left-hand side in Figure 6-13. An access via *general design activities* as presented in the past by Franke et al. (2003) is requested. The implementation is simple within the method specific access attributes. Beside this cluster, the task / situation and team / user specific attributes serve as a cluster to contribute to method accessing attributes (boxes in the middle of Figure 6-13). So, the requirement on the consideration of diverse boundary conditions can be fulfilled. A special access for the team-oriented approach is the use of the team or user profile for a method search. The idea is that the team, when characterised with the help of the assessment tool (see Section 6.2.1), can use the resulting profile as input for a method search. All in the profile characterised attributes are then set as a search option.

On the right-hand side of Figure 6-13, the different used access types for the team-oriented method access are highlighted. The topmost type is the user-defined text. The user of the tool can type self-defined words to search for a method. Within the three clusters, a combination of reduction filter and relevance filter is applied for realising the search options. The aim is on the one hand to display only methods that correspond to certain exclusive attributes but on the other hand to present a ranking of methods regarding further non-exclusive attributes. In general, this leads to fewer results but more suitable ones. To make the accessing attributes in the three mentioned clusters better understandable, additional questions are formulated. As an example, the attribute *method experience* is added by the question *"How much experience do the persons have with methods?"* The last presented access type in the team-oriented method provision tool is a list showing all methods contained in the tool. Summing up, four different access types are proposed to the user to offer multiple options.

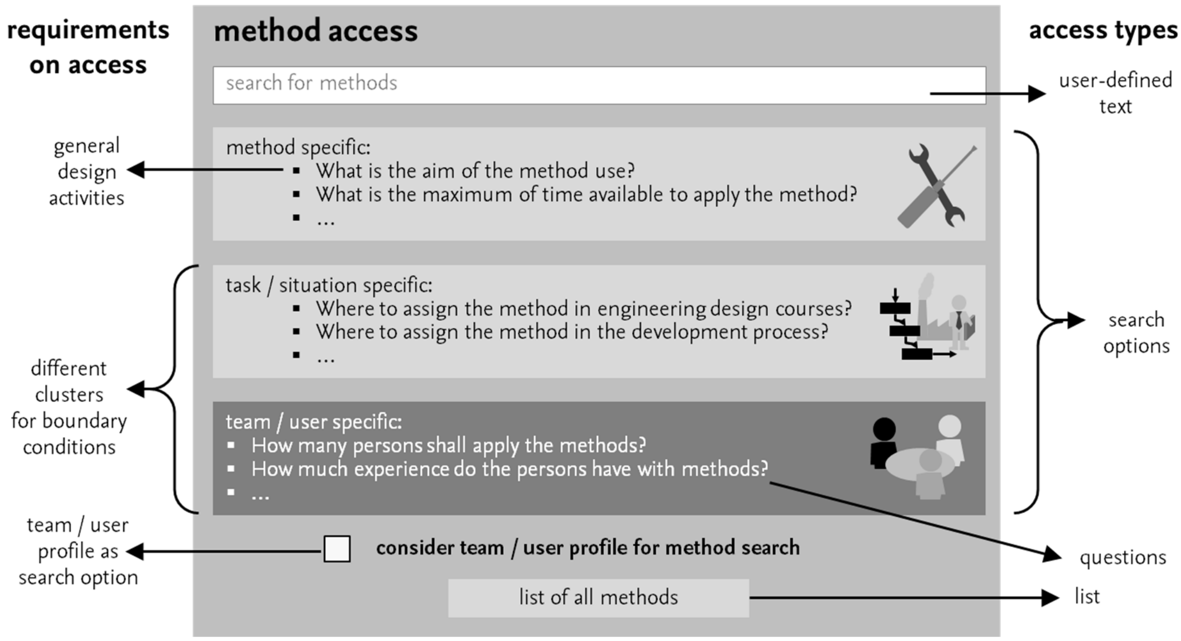


Figure 6-13 Conceptual structure of a method access considering team / user specific attributes

Algorithm for search options

After having considered the previously gathered requirements and the access types, further requirements for the search algorithm are considered. As already mentioned, a combination of reduction and relevance filter is used for the method access. This is a result of the requirement that the methods suggested according to a user query shall suit superior attributes like the *method aim* but also less important attributes like some team aspects. The superior attributes lead to an exclusion of methods whereas the other access attributes determine the relevance and, thus, the ranking of a method. In addition, the algorithm has to be stable with regard to non-selected attributes. This means that the algorithm delivers results of equal quality independent of the number of selected attributes.

To meet the formulated requirements, a multi-criteria procedure has to be the basis for the algorithm. A possible method is the utility analysis as it was proposed by Albers et al. (2015) for the InnoFox application. The idea is to define a utility value for each method regarding the user's query. The methods reaching the best utility values are recommended as suitable methods for the user and its situation. The general calculation of a utility value can be expressed as shown in Figure 6-14.

$$\overset{\text{utility value}}{U_i} = \underbrace{\boxed{\prod_{a=1}^{b} v_{ia}}}_{\text{reduction filter}} * \underbrace{\boxed{\sum_{c=b+1}^{d} (v_{ic} * w_c)}}_{\text{relevance filter}}$$

U_i *utility value of method* i
v_{ia} *value of attribute* a *for method* i
v_{ic} *value for attribute* c *for method* i
w_c *weight of value* v_{ic}

Figure 6-14 General calculation of the utility value of a method for a given user query

For the team-oriented method access a set of attributes from method specific as well as task / situation specific attributes were chosen as an example of commonly used method access attributes:

- *method classification*,
- *methods aim* (formulated as *general design activities*),
- *time effort*,
- *complexity of the upcoming task*,
- *process phase*.

As team-oriented attributes all of the attributes contained in the team-oriented method model were taken.

In the next step, the attributes leading to an exclusion of a method from the ranking were identified within an expert talk of a method expert from research and another from practice. The *method classification* and the *method aim* were identified as exclusive attributes. In addition, the attribute *team size* was considered relevant regarding the information whether the method is applicable alone or only in a team. So, a distinction between the value »1« and all other values was made for the exclusion of a method.

The value of an attribute v_{ia} is binary. If the selected value of an attribute a is suitable for the method i, v_{ia} is »1«; if not, v_{ia} is »0«.

For the values of the non-exclusive attributes v_{ic} the three remaining method and task / situation specific attributes are also binary coded.

For the values of the team-oriented attributes the predefined values of each attribute used for the method description and within the team / user profile can be used. For this purpose, Figure 6-15 presents a matrix assigning values for each team-oriented attribute to selected methods. According to the method description a check mark, an exclamation mark and a cross are used. The check mark equals the value $v_{ic}=1$, the cross the value $v_{ic}=0$. Inbetween the exclamation mark represents the value $v_{ic}=0.5$ if adaptions of the method are necessary due to the attribute's value. The content of this matrix is already part of the team-oriented method descriptions. This matrix concentrates all information required for the team-oriented method access in one table. According to the shown structure, assignments for further methods can be done. The complete matrix containing all team / user specific attributes for selected methods can be found in Appendix C4.

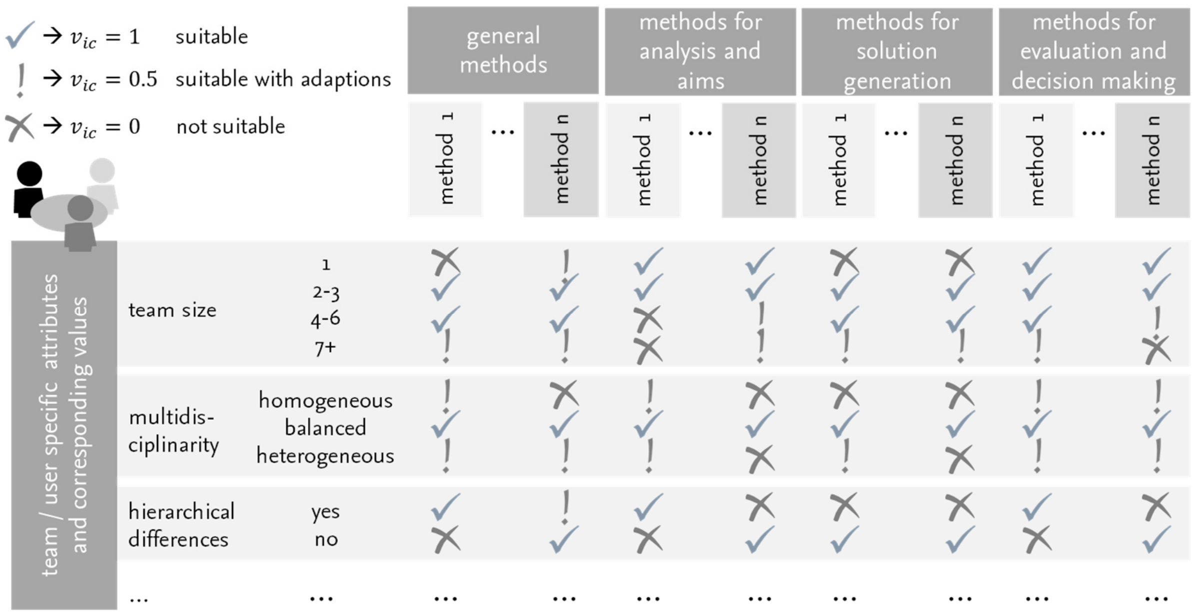


Figure 6-15 Schematic matrix for assigning values v_{ic} for team / user specific attributes to selected methods

Note that there are no complete matrices of further method access and descriptions for single methods provided in this thesis containing all presented attributes but only for team / user specific ones. The focus of the thesis is on the team-oriented method provision. The description and access of further attributes can be found in existing method collections as presented in Table 4-2 and Table 4-3.

Table 6-4 Attributes for the relevance filter of the method access and corresponding weights

attribute	weight (%)	attribute	weight (%)
required time	7,6	professional competence	9,3
complexity of upcoming task	7,1	social competence	4,4
process phase	5,8	method competence	6,2
team size	8,0	self competence	5,3
multidisciplinarity	5,3	local distribution	8,4
hierarchical differences	7,1	temporal distribution	8,4
culture	3,1	language	4,9
method experience	8,9		

The final step is the definition of weights for each of the attributes for the relevance filter. For this purpose, again the expert team conducted a pairwise comparison of the attributes. The result in terms of defined weights w_c is as demonstrated in Table 6-4. The complete pairwise comparison is part of Appendix C5.

Detailed view on the method access by method user characteristics

For a proper usability within a web-based tool, the access possibilities to team / user specific attributes are represented in a detailed view in Figure 6-16. Before, only the cluster, attributes and values as well as access types were named; now, for each of the team-oriented attributes the access via a question is shown. At the bottom of Figure 6-16, the access option via the team or user profile is located. This means that the before registered profile using the assessment tool is the basis for the method search. The team / user profile search contains team characteristics, competencies and collaboration characteristics. It shall only be accessible when logged into the web-based tool. If not logged in, the other search options using the questions are available. These options cover team characteristics and *method experience* as well as collaboration characteristics. Competencies are not provided as no profile is available to match the method requirements on competencies.

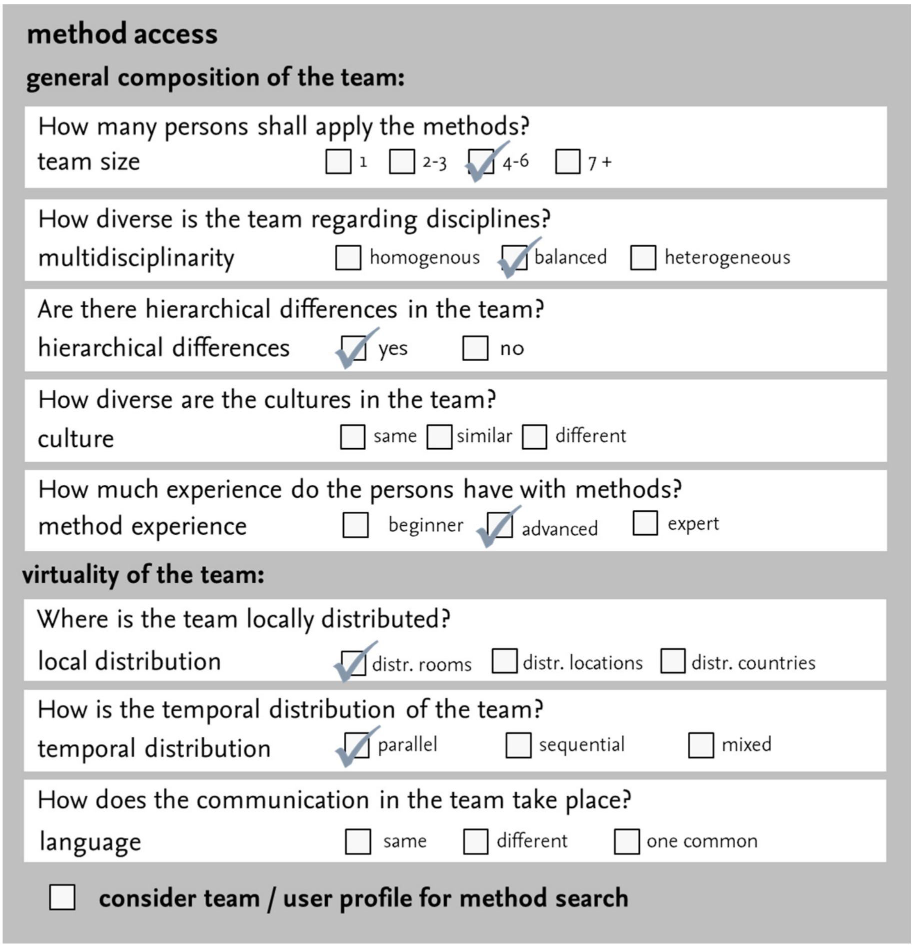


Figure 6-16 Team-oriented access attributes

A proposition on how the comparison between the team profile and the method's requirements on a team could look like was presented earlier by Bavendiek et al. (2016a). They completed the matrix of methods and method user characteristics correlating also communication technologies to each of the other categories. They also used the correlation proposed by Schleidt and Eigner (2010) between collaboration characteristics and competencies which is not considered in this research work. An extension of the presented method access through communication technologies is conceivable. Here, the method description is supplemented by adaptions and variants for distributed teams that include, amongst others, possible communication technologies to support the method application.

6.2.4 Interim conclusion

To conclude, the research question Q4 shall be referred to: *"How can method user characteristics be identified and considered in method provision and application?"* The concept for the team-oriented method provision tool consists of three main elements: the assessment tool generating a team / user profile, the method description model including method descriptions and the method access algorithm. For each element, the involvement and reference to method user characteristics were explained and demonstrated. The assessment tool helps to identify the relevant method user characteristics by using simple enquiries, self-perception and the established Competence-Reflection-Inventory. The second part of Q4 demands for an appropriate consideration of these aspects. For this, a team-oriented method model using all relevant team / user specific attributes was proposed. These attributes can then be utilized to access methods. There are two general options: accessing the methods via the team profile or selecting individually important aspects of the team and use them as search options. Thus, the method provision, including method description and method access, is presented in a team-oriented way allowing the consideration of relevant method user characteristics.

6.2.5 Exemplary scenarios

In this section, it shall be clarified how a team-oriented method provision tool based on the proposed concept could be applied. Therefore, two different applications are presented. Next, an example for each application is demonstrated using a fictitious set of individuals. This set is combined to different teams subsequently. Figure 6-17 illustrates the two mentioned ways to apply the team-oriented method provision tool. The first way is the selection of a method for an existing team, see (1). Here, the task narrows the methods down to a remaining set of methods, for instance, to one method class. The method user characteristics are now used for the decision on one method. The second way to use the team-oriented method provision tool starts again with the task. The task defines the method or methods that have to be applied, e.g. a FMEA is requested by the customer or an innovation workshop takes place. In this case, the tool can use the correlation of the accessing team / user specific attributes reversely. The method to apply sets the required characteristics of the team. The team members can be composed in accordance with these requirements.

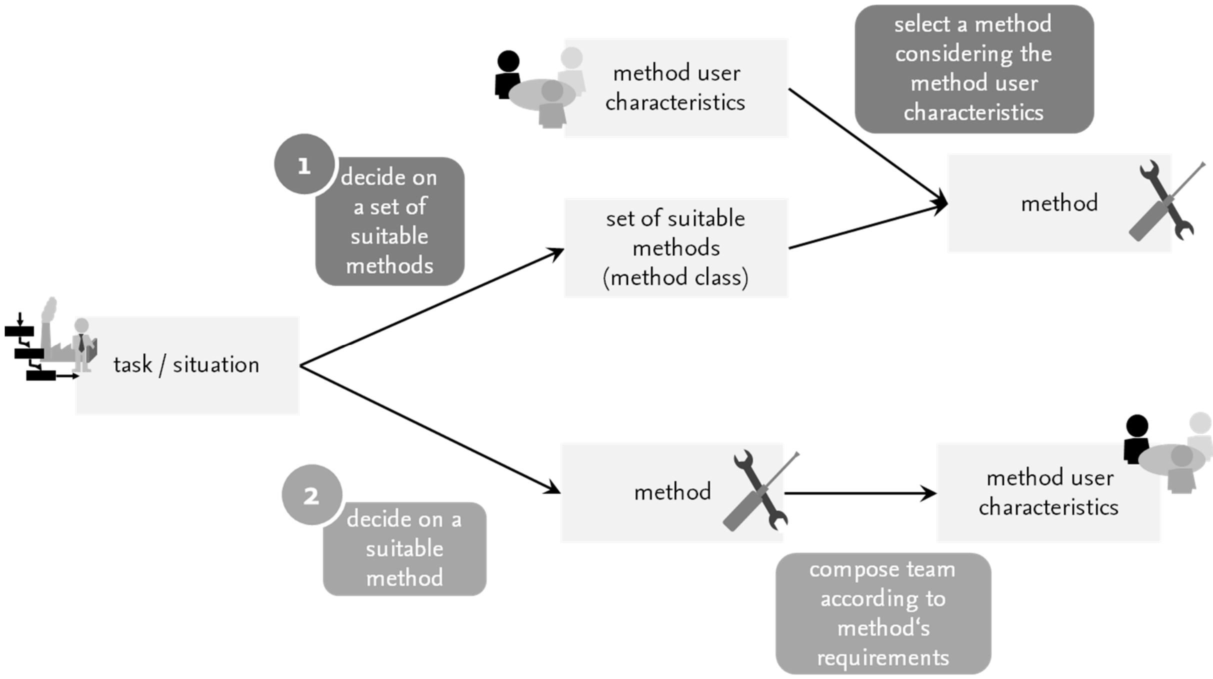


Figure 6-17 Two possible applications of the team-oriented method provision tool

The two exemplary scenarios are set up with teams from one company that holds differents sites. For the scenarios, ten persons from this company are described regarding the information needed for the team profile. First, the discipline or department as well as the position (manager or employee) are described. The cultural background, the method experience and information on local and temporal distribution are added. Finally language skills and the values resulting from the C.R.I. test are provided. This information on each fictive person is content of Table 6-5.

Scenario 1: Method for a team

The first scenario is a typical distributed development task. The team is composed of five persons from the sites in Braunschweig (Germany) namely no. 1, 2 and 9 and Pune (India) namely no. 3 and 4. The team's task is to find a new solution for an existing product on which the geometrical requirements have changed. Thus, the method class of ideation methods is chosen and will be considered in the following.

Table 6-5 Overview of ten fictive individuals belonging to one company which are used to form teams (P=professional, SO=social, M=methodological, SE=self-competence)

team members	discipline	position (hierarchy)	cultural background	method experience	site	time zone	languages	competencies			
								P	SO	M	SE
1	development	manager	German	advanced	Braun-schweig	UTC +1h	German (MT) English (F) French (B)	92	65	70	78
2	development	employee	German	advanced	Braun-schweig	UTC +1h	German (MT) English (F)	69	64	89	83
3	development	employee	Indian	beginner	Pune	UTC+ 5h30	English (MT) Hindi (F)	89	52	52	74
4	production	manager	Indian	advanced	Pune	UTC+ 5h30	Hindi (MT) English (F)	74	58	72	90
5	production	employee	Polish	beginner	Hamburg	UTC +1h	Polish (MT) German (F)	82	51	53	78
6	production	employee	German	beginner	Hamburg	UTC +1h	German (MT) English (B)	56	70	73	52
7	design	employee	German	expert	Braun-schweig	UTC +1h	German (MT) English (F) Polish (B)	74	89	75	49
8	sales	employee	French	advanced	Braun-schweig	UTC +1h	French (MT) German (F) English (B)	88	74	67	60
9	sales	employee	German	beginner	Braun-schweig	UTC +1h	German (MT) English (F) French (B)	69	91	62	79
10	quality assurance	employee	German	expert	Hamburg	UTC +1h	German (MT) English (F) French (B)	75	75	90	83

The method user characteristics are presented in a team profile in Figure 6-18. The disciplines are balanced and there are hierarchical differences due to the two managers among the employees. The distributed sites result in a time difference of 4 hours 30 minutes and different cultural backgrounds (Indian and German). English can be spoken as common language. The method experiences are mainly »advanced« as three out of five are advanced. The average of each competence facet leads to good professional and self-competence (»average to above average«), »average« methodological competence and poor social competence (»below to average«).

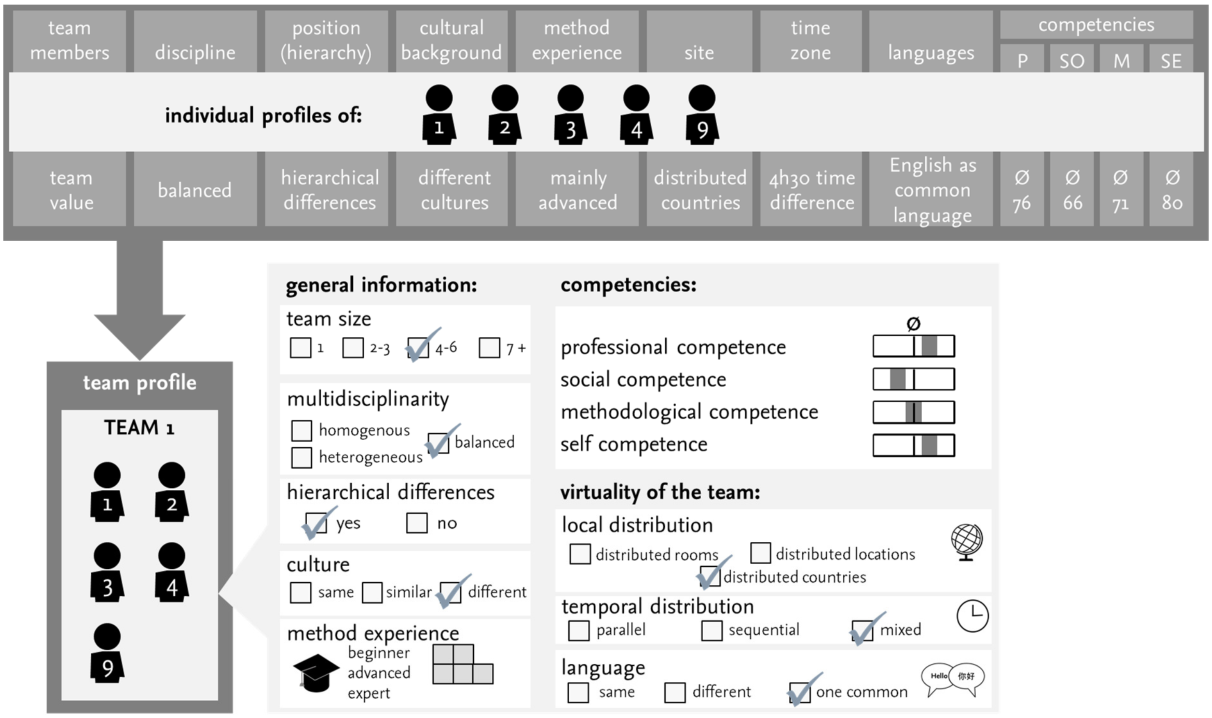


Figure 6-18 Team profile of team 1: method for a team

Using the complete profile of the team for the method access, the match with the five exemplarily described methods (Brainstorming, Gallery Method, Method 635, Synectics and Morphological Analysis) results in no match over all criteria (see Figure 6-19). The best fitting options are the Method 635 and the Morphological Analysis. The reasons can be explained by the low social competence and hierarchical differences in the team. Thus, methods without direct discussion are preferable.

The Method 635 has limitations due to the local distribution. As it is required to work with the ideas of the other participants, techniques that allow sharing sketched results are needed. The Morphological Analysis contains intuitive and discursive elements. Thus, its application with hierarchical differences in the team is not optimal. However, the method is easier to apply via video-conferencing and shared screen than the Method 635. Finally, the team gets two possible options that require adaptions. The advantage of the team-oriented approach is that the team is aware of possible challenges.

			methods				
			brainstorming	gallery method	method 635 (brainwriting)	synectics	morphological analysis
team/user attributes	team size	4-6	✓	✓	✓	✓	✓
	multidisciplinarity	balanced	✓	✓	✓	✓	✓
	hierarchical differences	yes	✗	✗	✓	✗	!
	cultures	different	!	!	✓	!	!
	professional competence	Ø to above Ø	✓	✓	✓	✓	✓
	social competence	below Ø to Ø	✗	✗	✓	✗	✓
	methodological competence	Ø	✓	✓	✓	✓	✓
	self competence	Ø to above Ø	✓	✓	✓	✓	✓
	method experience	advanced	✓	✓	✓	!	✓
	local distribution	distributed countries	!	!	!	!	!
	temporal distribution	mixed	!	!	!	!	!
	language	one common language	!	✓	✓	!	✓
		rating	✗	✗	!	✗	!

Figure 6-19 Matching the profile of team 1 to ideation methods

Scenario 2: Team for methods

The second scenario aims at identifying suitable individual profiles for a method application. An example is the realisation of an ideation workshop for a new product idea of the company. For this workshop, the set of methods to be applied is already set. The workshop shall start with the Persona method to generate potential users of the new product. Within the ideation phase, the Gallery Method and the Morphological Analysis shall be used. The evaluation of the ideas is done afterwards with a smaller core team. Subsequently, the requirements on the team are set by the Persona, Gallery Method and Morphological Analysis as illustrated in Figure 6-20. The workshop language is defined to be German.

A possible team of »4-6« persons should be located in Germany as the core competence of the development department is situated in Braunschweig (Germany). The team should be »heterogeneous« in its composition of disciplines and have preferably »no« *hierarchical differences* and »similar« cultural backgrounds. The requirements on *professional* and *social competence* are quite high. The common *language* within the workshop has to be German. To build a team of six persons, the colleagues from Hamburg have to be included in the workshop as only four persons from Braunschweig (without *hierarchical differences*) are available.

team/user attributes			persona	gallery method	morphological analysis	rating
	team size	4-6	✓	✓	✓	✓
	multidisciplinarity	heterogeneous	✓	✓	✓	✓
	hierarchical differences	no	✓	✓	✓	✓
	cultures	similar	✓	✓	✓	✓
	professional competence	Ø to above Ø	✓	✓	✓	✓
	social competence	Ø to above Ø	✓	✓	✓	✓
	methodological competence	Ø	✓	✓	✓	✓
	self competence	Ø	✓	✓	✓	✓
	method experience	beginner	✓	✓	✓	✓
	local distribution	distributed rooms	✓	✓	✓	✓
	temporal distribution	parallel	✓	✓	✓	✓
	language	one common language	✓	✓	✓	✓

Figure 6-20 Identifying required method user characteristics by the given set of methods

Looking at the team profile including person 2, 7, 8, 9 and 5 and 10 from Hamburg, the required competencies and characteristics are met (see Figure 6-21). This composition demands that the colleagues from Hamburg travel to Braunschweig (about 2 hours time) or the workshop is held virtually.

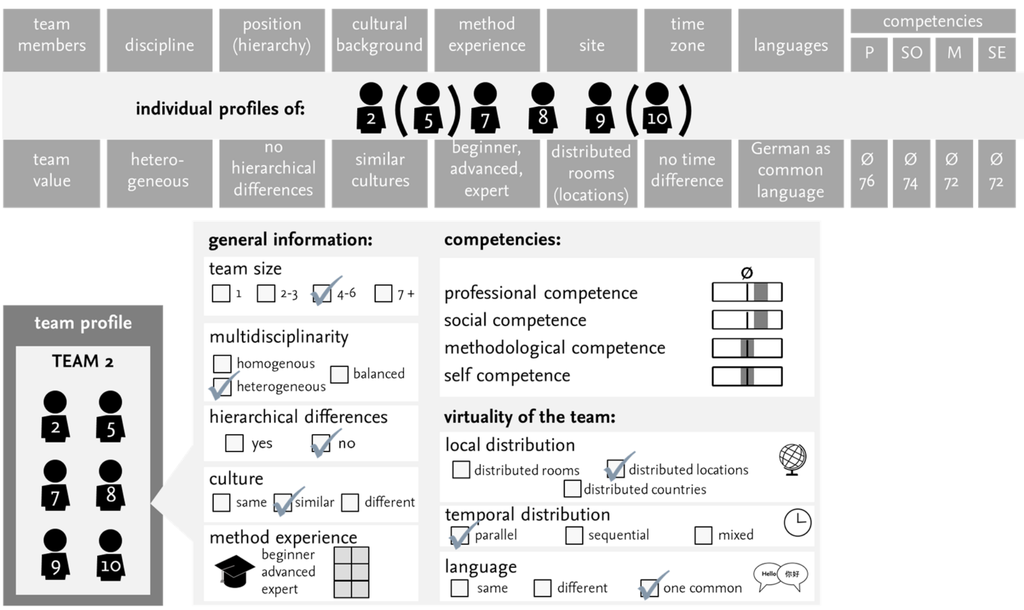


Figure 6-21 Team profile for a possible team 2 for the ideation workshop (P=professional, SO=social, M=methodological, SE=self-competence)

6.3 The method portal METHODOS as a software demonstrator

To test and evaluate the prior described concept for a team-oriented method provision tool, a software demonstrator was developed at the Institute for Engineering Design (TU Braunschweig) from October 2014 until October 2015 (first launch). Since then, the software demonstrator has been continuously improved but not all of the features presented in the concept have been implemented yet. The development was partly funded by the Department of Mechanical Engineering, TU Braunschweig. The development efforts were mainly supported by students and student research assistents. Thereby, a Django framework (Django Software Foundation, 2005), coded in Python (Python Software Foundation, 1991) was used. As the web-based tool is integrated into the homepage of the institute, the corporate design of TU Braunschweig was applied.

The software demonstrator was called METHODOS following up the research project “GINA - Holistic Innovation Processes in Modular Enterprise Networks“, in which a first method portal named “Methodos” was developed in 2003, e.g. Franke et al. (2003), Franke (2005). The primary target group of the new METHODOS are students of TU Braunschweig, mainly in engineering design. Thus, a first version of the software demonstrator was introduced to an engineering design course during the winter semester 2015/2016.

6.3.1 METHODOS as method provision tool for teams

The software demonstrator comprises a team-oriented method description and method access to more than 35 methods in German and English language. Both parts will be explained in the following sections. Moreover, it is possible to create a user profile. For reasons of data protection, a connection of multiple profiles to a team profile is not realised in the software demonstrator. Hence, the evaluation of a search via the team profile cannot be performed as proposed. Another type of evaluation will be presented instead.

The welcome page of METHODOS (see Figure 6-22) gives an overview of all features:

- The “method search” provides different options for a method access.
- The “list of methods” is another possibility to access the methods directly.
- The “introduction” facilitates the access using a short video on all features of METHODOS.

- The "procedural model" contains a description on how to proceed within a general engineering design process.
- "My profile" allows the user to store user data in the style of the user and team profile.
- "Glossary and literature" cover requirements on additional content. This subpage provides method independent literature and explanations on important terms used in the method descriptions.

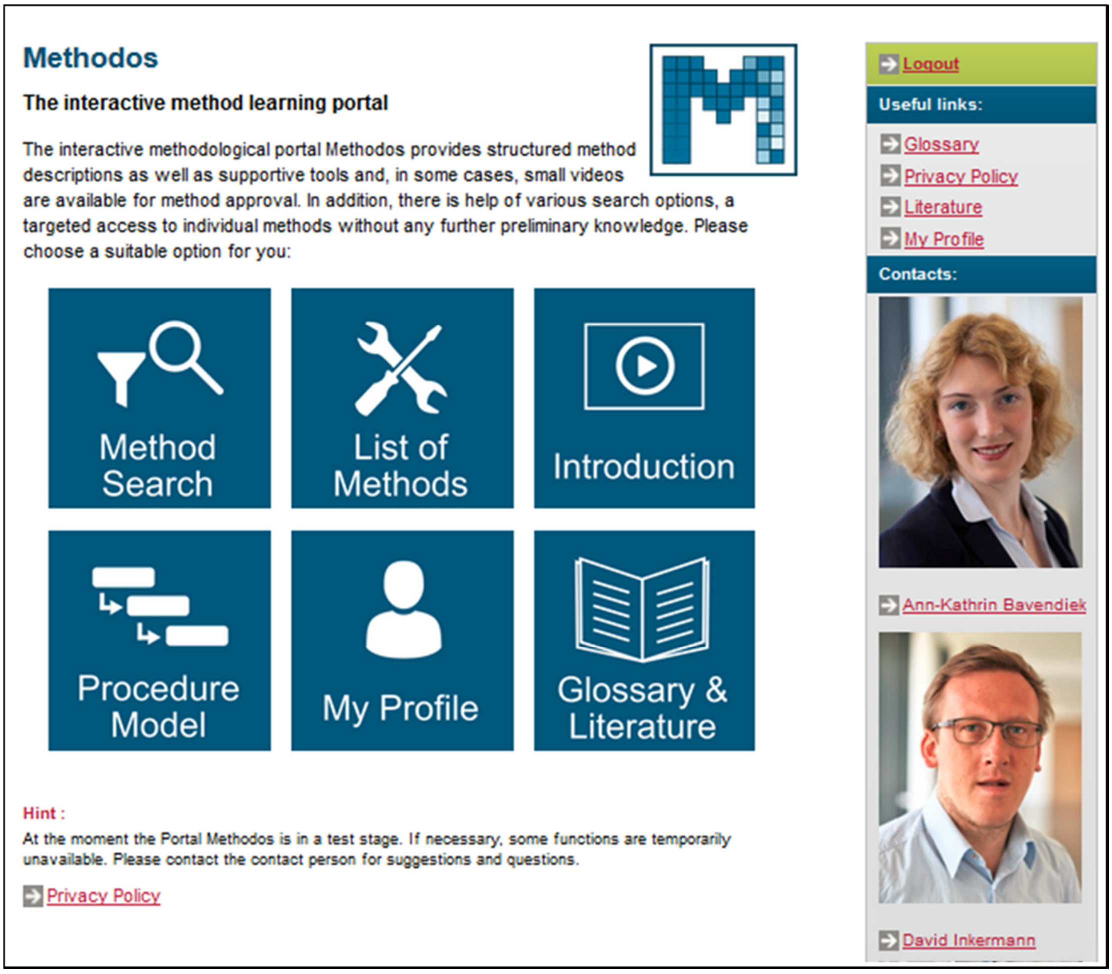


Figure 6-22 Welcome page of the software demonstrator METHODOS, available at https://methodos.ik.ing.tu-bs.de/

6.3.2 Method descriptions in METHODOS

The earlier presented team-oriented method description model was mapped to the software demonstrator in most cases directly. The shape of the model could not be transferred to the corporate design. Thus, the attributes were grouped and represented in drop-down menus or in the sidebar on the right-hand side. Figure 6-23 demonstrates at the example of the method Synectics a method description in METHODOS. The method content is limited to the main content blog and the right sidebar. Starting with the main content, the *method name*, the *description* and an *illustration* are presented. The *short description* is only shown in the list of methods. Below this short introduction to the method, the drop-down menus follow with detailed information. The *procedure* of the method is described by a step-by-step description. Additional *hints* for the application are given. Next, *videos* on the method and its application are provided like they were described by Reiss et al. (2017) (see also Section 7.1.1). The drop-down menu "additional resources" contains *tools and templates or links* to them. These can be forms that facilitate the method application or one-page instructions (see Section 7.1.2). The subsequent drop-down menu shows *practical examples* and allows the upload of own examples. *Strengths* and *weaknesses* are listed as bullet points in a separate menu. The next drop-down menu contains information on the requirements for the team that applies the method. Mainly collaboration characteristics are implemented like *location* and *time* as well as team characteristics like *multidisciplinarity* and *hierarchical differences.* Additional references comprise *literature* recommendations especially for the method. The last drop-down menu called *comment* allows the user to rate the method (*evaluation function*) and to write a comment. Below the drop-down menus, *similar methods* are shown. These can be accessed via a link directly.

The topmost feature on the right-hand sidebar is the log-in and log-out button. The user administration of METHODOS is connected to the Lightweight Directory Access Protocol (LDAP) of TU Braunschweig. In this way, the access is administrated externally; members of TU Braunschweig do not need another user account.

Below the login, relevant information on resources for the method application is presented. This information is:

- *time effort* and *preparatory effort,*
- *training effort*,
- *team size*,
- *moderator*,
- *materials required*,
- *self documentation*, meaning if models are obtained somehow through the method application.

The subsequent bar reveals information on the *method aim*, the *method classification*, the corresponding *process phase*, using the Braunschweig Procedural Model (Franke et al., 2006), and the assignment to the engineering design courses, in which the method is taught.

Figure 6-23 Screenshot of a method description in the software demonstrator METHODOS

The next bar illustrates the required *method experience* of at least one team member to apply the method without problems. At the bottom of the right-hand sidebar, the *complexity of the upcoming task* and the *orientation of results* as it was introduced by Strasser (2004) are illustrated. A detailed description focussing on the interactivity of the web-based tool is given in Bavendiek et al. (2016b).

Summing up, the team-oriented method description model is not implemented completely in the software demonstrator. Method user characteristics like the competence facets, *culture* and *language* are missing. They will be integrated in future work. Nevertheless, most of the attributes proposed in the method description model are used in the software demonstrator which allows the realisation of some tests (see chapter 8).

6.3.3 Method access in METHODOS

After having addressed the method description, the method access within the software demonstrator METHODOS shall be the focus. As introduced earlier, the method search button on the welcome page comprises the method access as intended in the team-oriented method provision tool concept.

There are different types of access realised as illustrated in Figure 6-24: a user-defined text search via keywords or method names and filters using additional questions to improve the understandability. The layout again utilizes drop-down menus to group similar questions or attributes. The topmost group contains the *method classification* and the *method aim*. The *general design activities* are used to formulate the *method aim*. Subsequently, team relevant attributes (*team size* and *method expierence*) can be selected. There are no more team attributes used in the current version of the software demonstrator. Further search options rank the relevance of the set of methods by *time effort*, *materials required*, *complexity of the upcoming task*, *process phases* and for students the assignment to certain engineering design courses. The number of resulting methods due to the selected filters is displayed on the filter button. In this way, the user can see the effects of their selections. In the next step, when the search results appear, the accordance with the search query of each method is displayed. Finally, all methods in a list can be accessed via a link on the bottom of the search options.

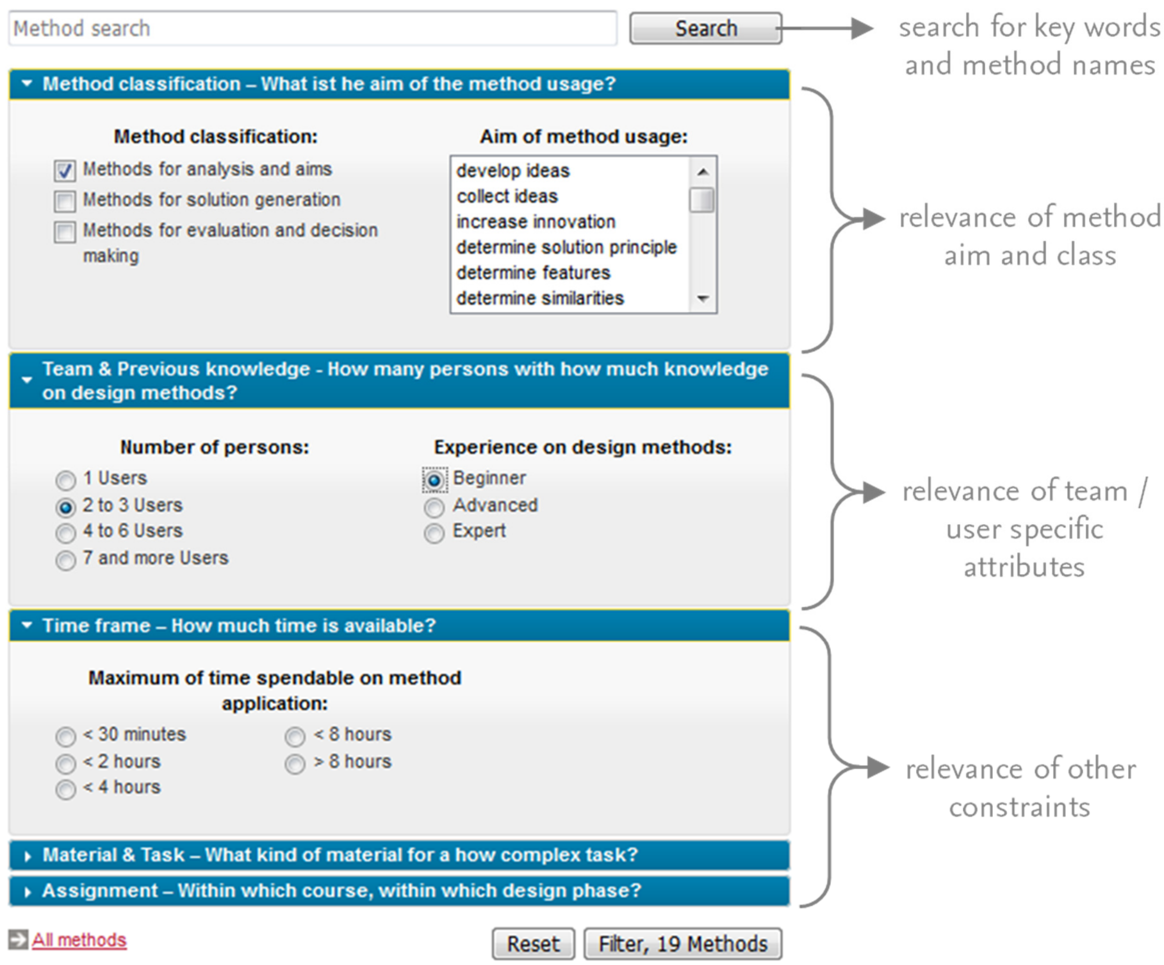


Figure 6-24 Screenshot of the method access in the software demonstrator METHODOS

6.4 Reflection on research questions

Chapter 6 proposed answers to research question Q3 and Q4 dealing with the influence of the design team on the method application and the subsequent consideration in method provision. Main findings will be summarized and reflected for each question:

Q3 *"How do method user characteristics influence the methods' application in engineering design?"*

- Mainly the question which characteristics of the method user and the team influence the method application rather than the way (how) of the influence was analysed. The way of influences were the basis for the sensitivity analysis.
- The answer to this research question demands expertise from different disciplines, namely engineering design and design methods as well as psychology and collabo-

ration aspects. Thus, the sensitivity analysis was conducted with an expert team consisting of experts from different disciplines.

- The aspects of a team found to be relevant for method applications are *team size, multidisciplinarity, hierarchical differences, cultural differences, professional, social, methodological* and *self competence, method experience, location, time* and *language.* An impact factor belongs to each aspect building a complete impact model.

Q4 *"How can method user characteristics be identified and considered in method provision and application?"*

- The above-mentioned aspects were introduced as team-oriented attributes to describe and access methods. Only two of the aspects (*team size* and *method experience*) have already been considered in some existing method collections. Thus, the contribution of the thesis is the integration of a complete set of team-oriented attributes for method provision.
- For the consideration of method user characteristics an access algorithm including all relevant team-oriented attributes was proposed. It is directly transferable to a web-based implementation. For the usage in a paper-based method collection it is not suitable due to the high calculation amount.
- For matching the attributes to the method user characteristics, a concept for an assessment tool for determining the relevant aspects was proposed. Therefore, existing assessment tests, self-perception and simple enquiry are used to identify the values of the team-oriented attributes.
- The applicability of the team-oriented method description and access was demonstrated at two exemplary fictive scenarios. The team-oriented attributes influence the result of a method selection. The application with an industry partner showed similar results.
- A software demonstrator covering most of the elements conceived for the team-oriented method provision tool was developed. This demonstrator was introduced in design education, which will be described in the subsequent chapter for a training concept for methods. It will also be used for evaluation purpose in chapter 8.

7 DEVELOPMENT OF CONCEPTS FOR TRAINING DESIGN METHODS

"The only source of knowledge is experience."
Albert Einstein, German physicist

This chapter aims at the development of successful training concepts for engineering design methods. These training concepts shall provide the opportunity to gain experiences with methods through their application. The underlying assumption for this chapter is A3: *"To achieve a successful method knowledge transfer the target group has to be considered."* This assumption is mainly based on previous research of researchers around Birkhofer, e.g. Lenhart and Birkhofer (2006) or Jänsch and Birkhofer (2007), who investigated the influence of the user's expertise level on learning and training processes. They proposed advice on how to design different material for training purpose considering the user's knowledge level.

To build on these research works and to answer research question Q6: "*What are successful means for method knowledge transfer considering the target group?"*, different training concepts for different target groups (design education and practice) will be developed in this chapter. Therefore, general didactic method training media and formats will be presented in Section 7.1 (see Figure 7-1). The created media and formats will be checked against the previously listed general requirements (see chapter 5) on successful design method transfer and training. To address the target group specific requirements (see chapter 5), Section 7.2 proposes training concepts for design education using some of the generally introduced elements as well as the method provision tool from chapter 6.

Figure 7-1 Schematic illustration of the chapter's structure

The subsequent Section 7.3 offers training concepts for traditional and virtual transfer workshops using also the method provision tool. Both training concepts for design education and practice will be considered with regard to the requirements set up for the target group in chapter 5. Section 7.4 concludes the chapter and reflects on the research question Q6.

7.1 General didactic method training media and formats

Before presenting complete training and transfer concepts for methods in design education and practice, this section deals with individual elements that can be included in the training concepts. The first element is the method provision tool, which was already described in detail in chapter 6. Subsequently, further general media and formats will be developed and demonstrated with the aid of examples. These media and formats are independent of the target group, thus, they shall fulfil the general requirements on method knowledge transfer. The following sections present method videos, instructions on methods as well as little software tools and templates for method application. All these elements are provided via the method provision tool METHODOS as additional content and tools.

7.1.1 Method videos

Method videos are explanatory videos that explain and demonstrate the application of a method; for a detailed description see also (Reiss et al., 2017). Method videos are short videos of a maximum duration of seven minutes for conciseness reasons (Reiss et al., 2017). The main elements are pictures, animations and keywords as visual information using simple Microsoft PowerPoint slides as basis. All method videos developed at the Institute for Engineering Design (TU Braunschweig) present the protagonist called Tom who is an engineering practitioner. He usually is confronted with a problem, which he solves by applying the method to be explained. Thus, the story around the protagonist clarifies the context and gives a structure to the audience. As demonstrated in Figure 7-2 (right-hand side) at the example of the Synectics method, an overview of the method is presented for a better clarity of the structure. The pictures and animations used are simple and easy to remember for recognition value. The story around the protagonist is told by a narrator off-camera for additional aural information. Finally, to complete the four aspects of Langer et al. (2015) on comprehensible design of media (simplicity, structure, conciseness, exhilarating supplements), the last element are exhilarating supplements for entertainment purpose like humorous components within the video (Nisse, 2016; Reiss et al., 2017).

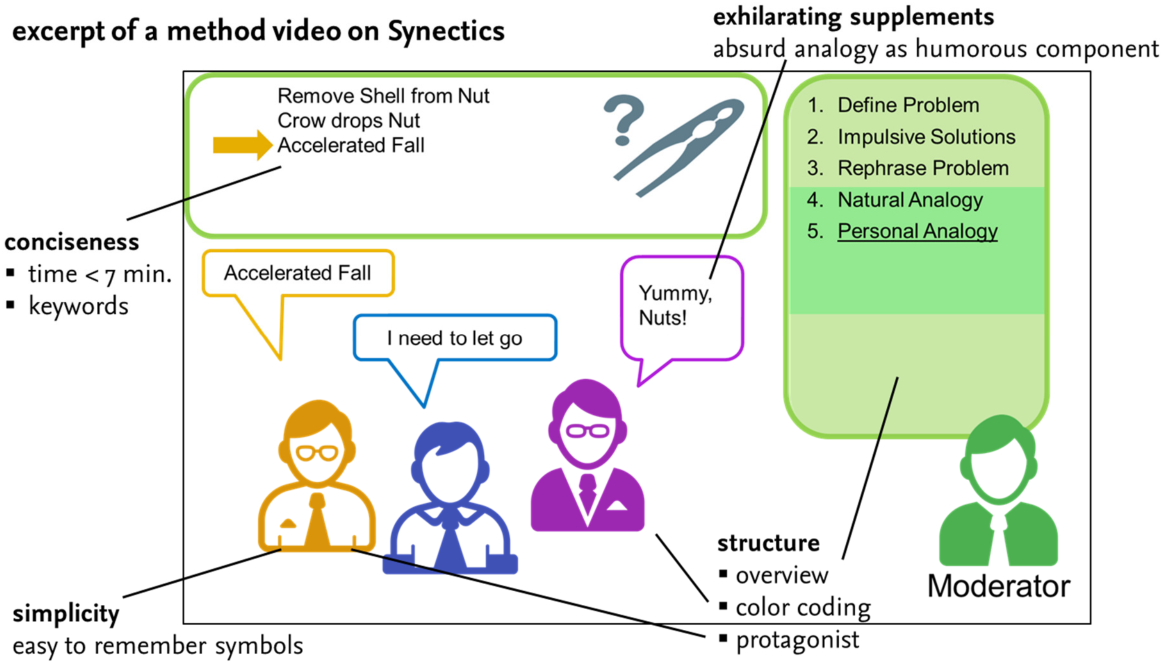


Figure 7-2 Screenshot of the method video on the Synectics demonstrating the underlying arrangement (Reiss et al., 2017)

Reiss et al. (2017) demonstrate how method videos fulfil success factors on method knowledge transfer. Building on this, Figure 7-3 presents requirements on method knowledge transfer (grey outer boxes) from chapter 5 and maps them to elements or characteristics of method videos (in the centre of Figure 7-3). Using the context of the story around the protagonist, for instance, contributes to requirements like convincing people and usage of realistic examples. The story involves the audience and pretends to be an exemplary project just happening in another organisation. As a further example, short descriptions of the methods within the videos fulfil the requirements on focussing on essentials and results.

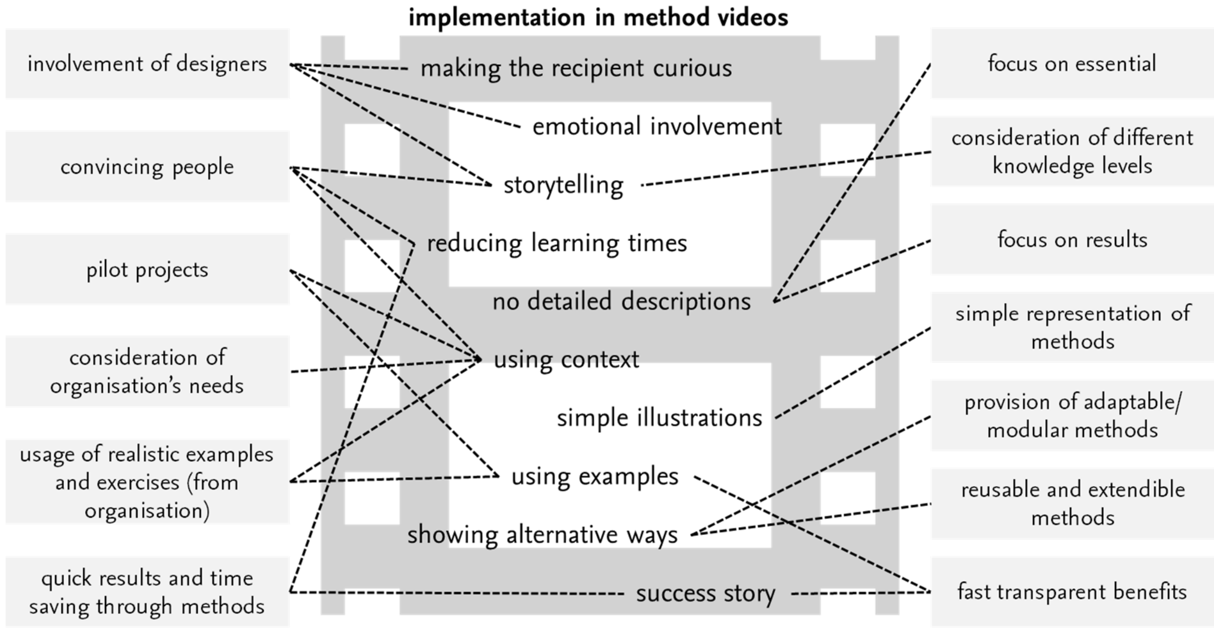


Figure 7-3 Mapping requirements on method knowledge transfer to implementation possibilities in method videos based on Reiss et al. (2017)

7.1.2 Instructions for methods

Inspired by the research work of Chirumalla et al. (2015) on different instruction media, by the proposition of an "Instruction" (German: Bedienungsanleitung) of Pulm (2004) and by assembly instructions of IKEA, the idea of developing instructions for engineering design methods arose. This kind of training medium is only adequate for simple methods due to the limited information representable in an instruction. At the example of the Method 635, such an instruction is demonstrated in Figure 7-4 to explain the structure and elements (Rau, 2015). The attributes for the method description are listed at the right-hand side. Beside the *method name*, *input*, *time effort, team size* and *material required* are used in the upper part of the instruction to shortly present the "elements needed" for the method application similar to the materials needed in assembly instructions of IKEA. The lower part of the instruction uses simple pictures to describe the procedure of the method.

The requirements that are fulfilled are mentioned on the left-hand side in Figure 7-4. Only simple methods are explained with the help of this medium. These methods are then simply represented by pictures and few keywords or explaining text. Due to the limited information amount, the focus on the essential is mandatory. Thus, the benefits are easy to recognise at the end of each instruction.

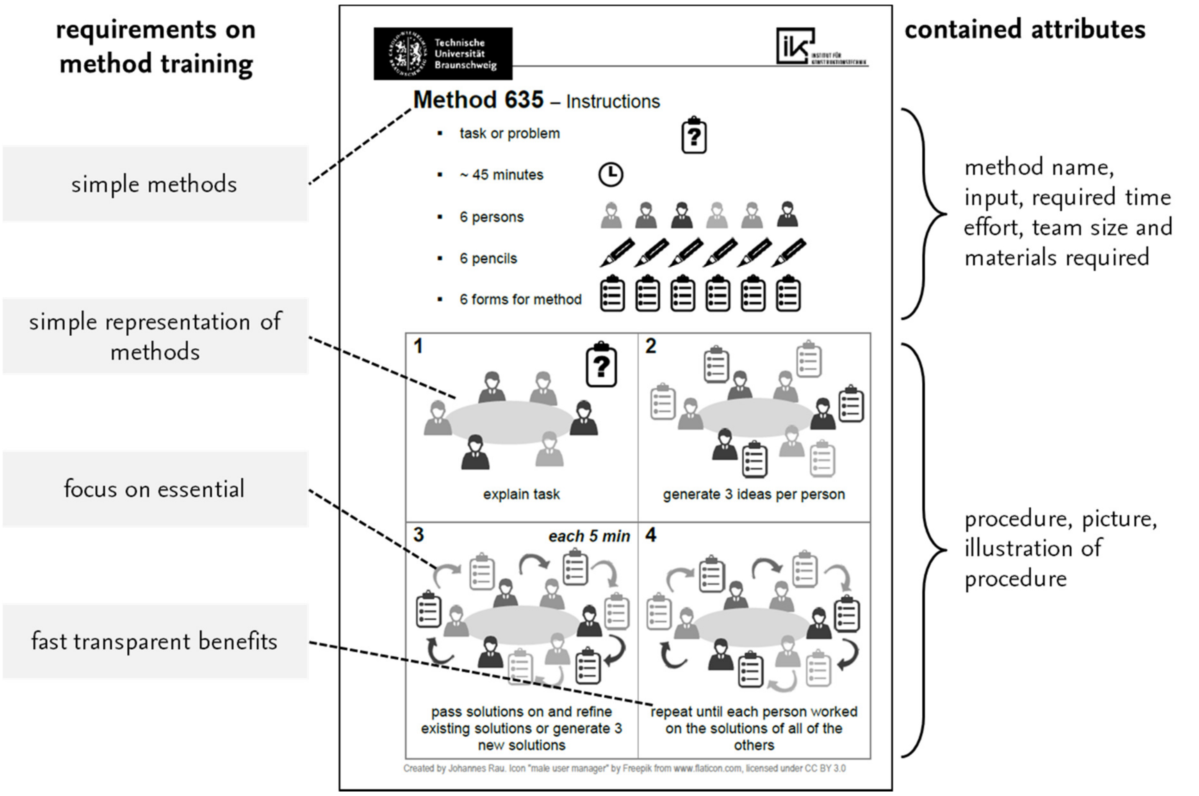


Figure 7-4 Assignment of attributes to method instruction (right) and mapping requirements on method knowledge transfer (left)

7.1.3 Software tools and templates

This section presents some software-based templates that facilitate the direct application of a method. The first element is an independently usable small program written to enable the learning and direct application of the method Point Rating System. The subsequent sections use existing software programs (e.g. Microsoft Excel, Microsoft PowerPoint) to provide templates for other methods.

7.1.3.1 Software tool for Point Rating System

Because of the success of learning software, a software tool supporting the application of the method Point Rating System was programmed using Visual Basics for Application (VBA). The tool explains the method step by step and provides direct action possibilities based on an example application. It is distributed as EXE (executable) file for download. A screenshot of the user interface is shown in Figure 7-5. To gain insights on the usefulness of such a software tool, a small evaluation comparing software tool, method video and lecture notes on the method was conducted within a design education class. Due to the poor evaluation results compared to the method video and the high effort to program the simple software tool as well as to install the tool on each device, future software-based templates were based on existing programs and implemented within those (e.g. Microsoft Excel files), see subsequent section (Wotzko, 2015).

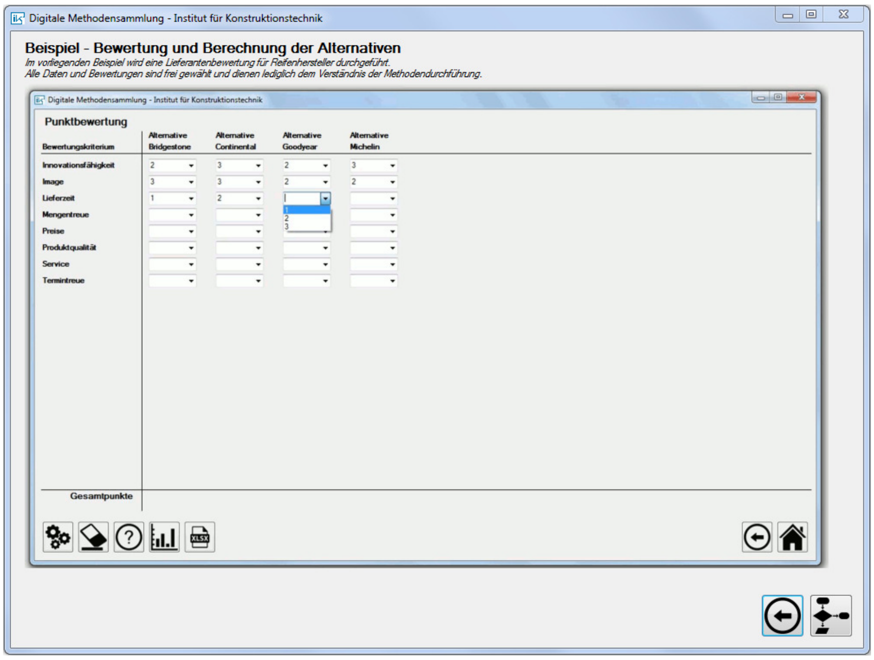


Figure 7-5 Example of the usage of the software tool (help function)

7.1.3.2 Excel sheets with macros

Due to the high standardisation and structure, many evaluation methods, e.g. Point Rating System, Cost–Utility Analysis and Pairwise Comparison, and some of the methods for analysis like Quality Function Deployment seem to be suitable to provide simple templates for direct application. Thus, mainly Microsoft Excel-based templates were developed for most of the basic methods. Some of these contain macros for an easier application and the merging of, for instance, multiple evaluation results to obtain average results, see e.g. (Springborn, 2016).

The requirements fulfilled by these software-based templates are first of all software supported approaches and offer training or action possibilities. As the method can be directly applied and is supported by the template, benefits can be quickly recognised. The templates provide only the information needed to apply them. Thus, a focus on results and on essential is given as well. The templates are flexibly adaptable to the organisation's needs or to student projects.

7.1.3.3 FMEA template for different level of experience

A special type of the software-based templates is the Failure Mode and Effects Analysis (FMEA) template. It considers the user's experience level as proposed by Lenhart and Birkhofer (2006). Besides the usual FMEA template, a simple "novice" version is included as an optional template. This novice version is reduced to the most relevant aspects of the FMEA to simplify the utilisation. Furthermore, guiding questions complete the headlines of each column. In this way, filling in the rows shall be facilitated. Automatic calculations (in both expert and novice version) prevent calculation errors. The detailed consideration of an improved status is missing. Instead, there is the possibility to checkmark the row if the measure for improvements was done, see (Sauerland, 2017).

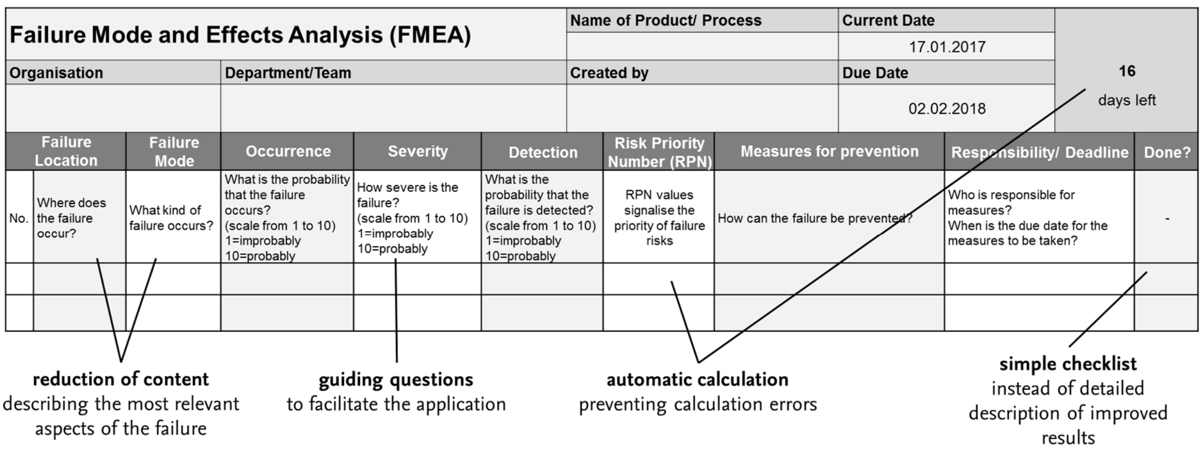


Figure 7-6 Novice version of the FMEA template with remarks on changes compared to original template

Additionally to the requirements fulfilled by the software-based templates, this template addresses the consideration of different knowledge levels.

7.1.3.4 Slides with template for General Function Structures

General Function Structures help to abstract technical systems based on their functions and main flows of energy, material and information. They are universally applicable (reusable and extendible) in the principle phase of a development process. However, they are rarely used by students and practitioners. One of the reasons mentioned is the missing possibility to easily represent the results in a neat manner (not drawn by hand). Hence, a software-based template was developed to provide direct action possibilities for the method application. In combination with general information on the method, its application and an exemplary application, a template with predefined symbols and connections was designed. As underlying software tool, Microsoft PowerPoint was chosen. The connection of presentation opportunities (for general information and exemplary application) and the template as "empty" slide was decisive (Nisse, 2016). Figure 7-7 illustrates the single elements of the template and assigns the fulfilled requirements on method knowledge transfer.

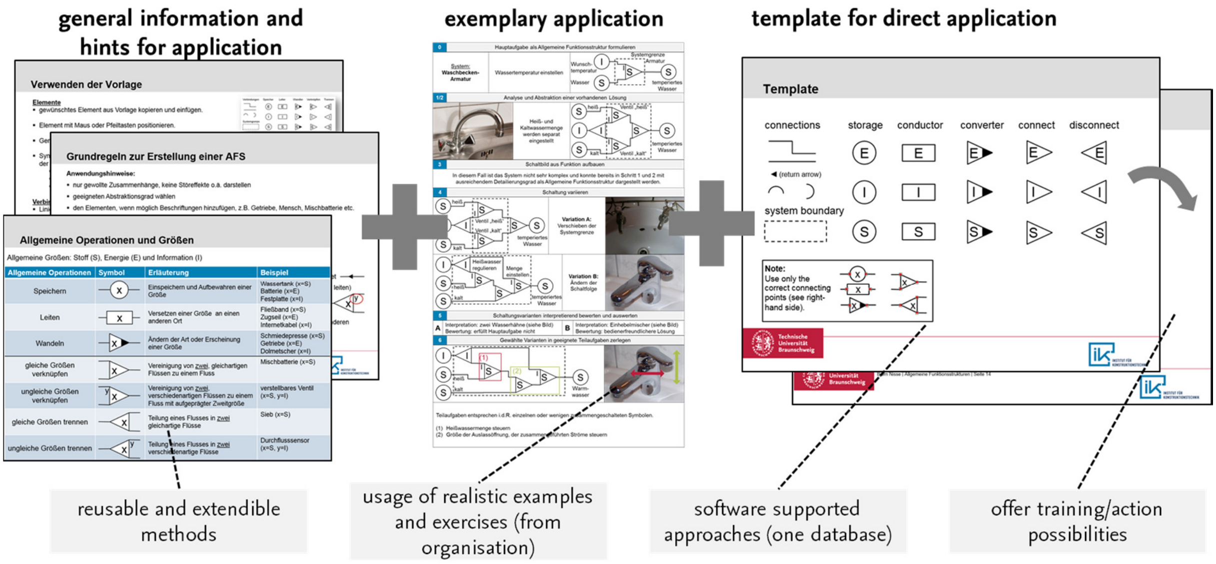


Figure 7-7 Elements of the slide template for the General Function Structures and mapping requirements on method knowledge transfer

7.2 Concepts for design education

After having presented different media for method knowledge transfer and training that mostly fulfil the requirements earlier defined, some of these media will be introduced within the method provision tool to design education courses. The general idea is to provide all methods taught during the studies in one web-based portal, which is the method provision tool METHODOS. In this way, there is one main source for all method descriptions, all method videos, templates and further assisting material on methods. The students at TU Braunschweig have free access. They are advised to use the tool from their first semester until their master's thesis. To do so, it is necessary to implement the portal into each course dealing with engineering design methods to give one central place to go for those methods. This general idea is represented in Figure 7-8 on the right-hand side. The idea considering the trainer or professor is to get feedback from the students on the method descriptions and other content (templates, videos, etc.). This is possible via the commentary and evaluation function of the method provision tool. Thus, a continuous improvement of the method provision tool can be achieved (Bavendiek et al., 2016b).

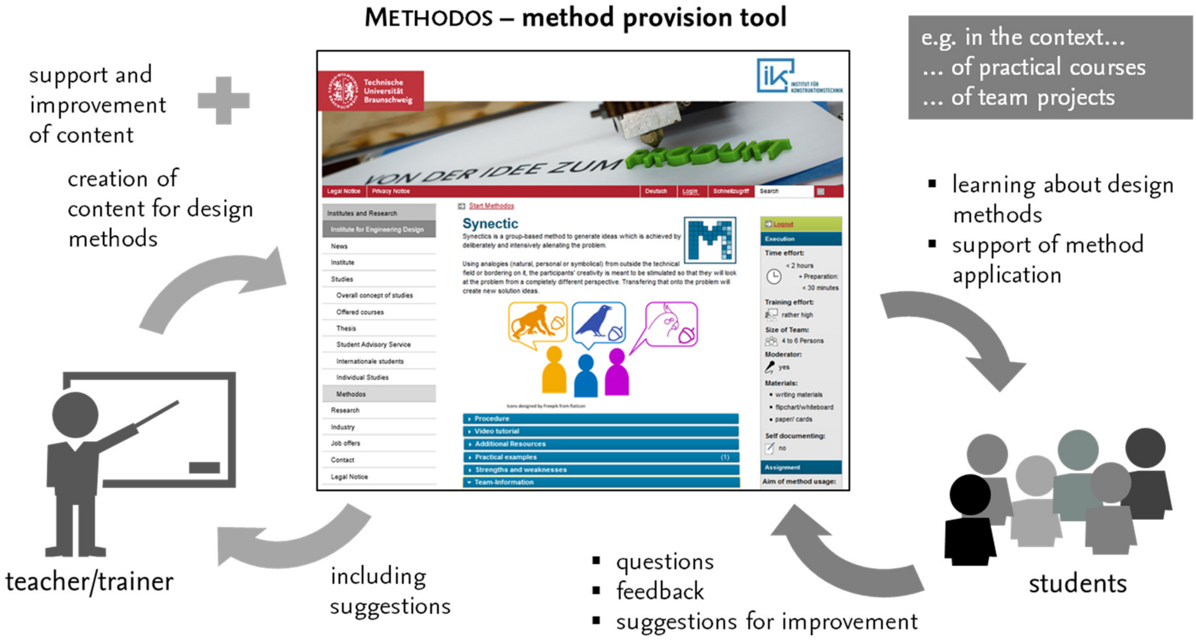


Figure 7-8 General idea of integrating the method provision tool into the courses

The following sections deal with the integration respectively the integration process of the method provision tool into a classroom-based course and an online course.

7.2.1 Integration of the method provision tool into classroom-based courses

The basic idea to integrate the method provision tool into the existing design education courses is the provision of methods at one central platform. This value for the students has to be pointed out. Furthermore, the method provision tool allows adapting the students' learning strategies. It provides many different opportunities to learn about a method and to apply it. Learners of different knowledge levels as well as with different perception preferences are addressed. In this way, it is possible to design a diversified course. By the aid of the practical examples, the methods are demonstrated in relation to relevant context. Using team projects and little exercises during the classes, the methods can be directly trained. The method provision tool can be used to provide the needed information on the methods before the application. Additionally, it can be integrated when selecting a method for a task because of the method access functionalities. In this way, the students are involved in the decision on the method. The diversity of media included in the method provision tool shall motivate the students to search for their favourite medium. Through modern media like videos and evaluation functions below each method, the attraction to the students shall be enhanced. The commentary function additionally animates the users to reflect on the method application and to share experiences.

For introducing the method provision tool in each course, a four-step approach was developed (see Figure 7-9). The first step is mentioning the tool within the first lecture of the semester when the structure and content of the course are explained. The second step is the demonstration of the tool when it is relevant for the first time in the course, e.g. the first method has to be explained. Here, a special video presenting the key aspect of the tool was created. In addition, the tool can be used to explain some or all of the methods. Within the third step, the method provision tool is applied. On the basis of an exercise respectively an engineering design task, teams of four to six students have to acquire the method given by the professor and subsequently have to apply it. Tutors assist the students if needed. The last step is another application of a method. But this time, the students working again in teams are advised to select an appropriate method on their own with the help of the access functionalities of the tool. Again, tutors assist the student teams. The fourth step can be repeated multiple times to train the students on diverse methods (Bavendiek et al., 2016b).

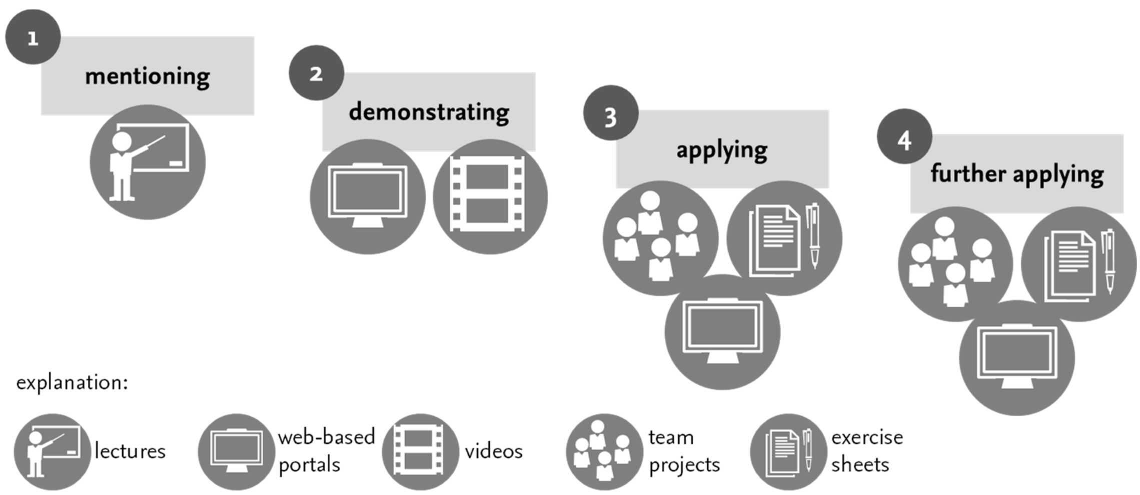


Figure 7-9 Steps to integrate the method provision tool into classroom-based courses as proposed by Bavendiek et al. (2016b)

7.2.2 Integration of the method provision tool into an online course

Beside the integration into the existing courses, a special online course dealing with engineering design methods was developed as a cooperation of TU Braunschweig and Leibniz Universität Hannover within a TU9[4] initiative. The aim was to create a Massive Open Online Course (MOOC) for all students of the TU9. A MOOC is an online course that provides free access to everyone and reaches many people. This particular online course was designed as a blended MOOC for students of Hanover and Braunschweig to enhance the course quality. According to Rovai and Hope J. (2004) a blended MOOC or blended learning is "a hybrid of classroom and online learning that includes some of the conveniences of online courses without the complete loss of face-to-face contact" (Rovai & Hope J., 2004). So, the blended MOOC combines in-class lectures with online learning material.

The elements of this online course are illustrated in Figure 7-10. The arrows in the centre of the figure demonstrate the course of the MOOC. At the beginning and in the end, there are in-class lectures held. After four weeks of providing new content, an accompanying team project starts. In this project, the previously learnt methods shall be applied to solve an engineering design task that changes every year. Besides the team project, homework and quizzes offer further application possibilities for methods. The method provision tool is another element of the online course and assists again the method acquisition and application. For the application, special tutorials or exercise videos are provided demonstrating the solution of an exemplary task. Other content around the methods, e.g. the procedure of design processes or the definition of technical systems, are offered as video lectures (Bavendiek, Ring et al., 2017).

In contrast to the in-class courses, there is no step-by-step introduction of the method provision tool. All elements of the course allow the participant to browse the material and use those materials preferred. However, the requirements for method knowledge transfer in design education are similarly addressed. A difference consists of the guidance on the team projects. Within the online course, the teams work on the task without assistance by a tu-

[4] The TU9 is a union of the nine leading German institutes of technology or technical universities (TU).

tor. They may contact the supervisor for feedback or help but there are no special slots within in-class lectures for teamwork. In fact, the students are placed in a situation with a high amount of self-studying, which corresponds to practical engineering work.

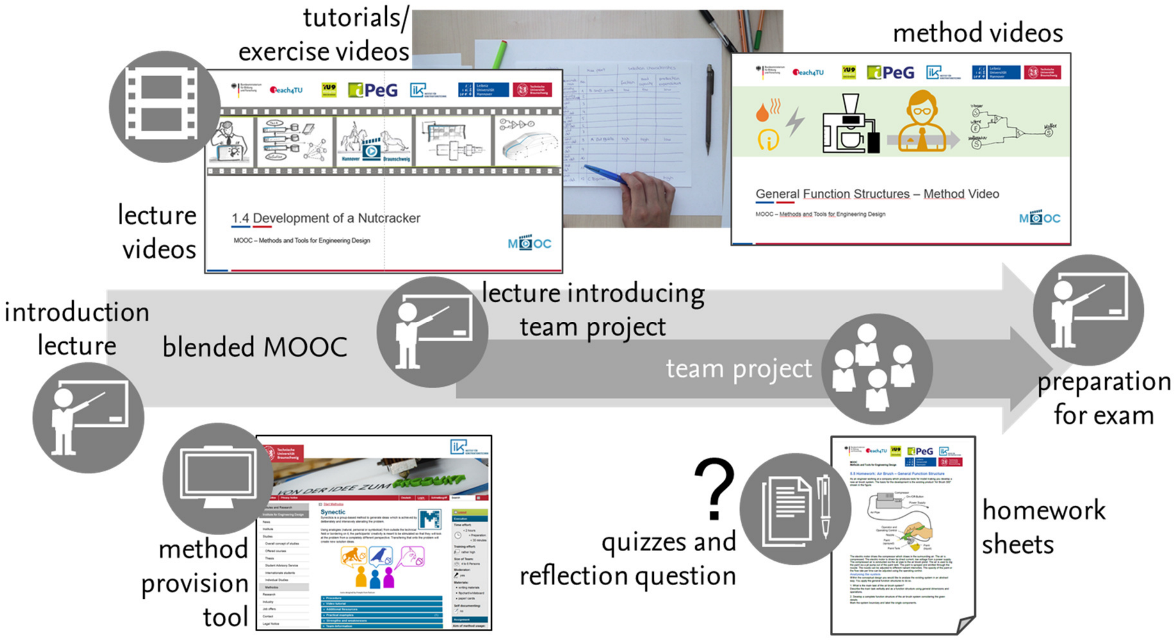


Figure 7-10 Concept and elements of the online course on design methods of TU Braunschweig and Leibniz Universität Hannover

7.3 A concept for training design methods in practice

In this section, special concepts for method knowledge transfer and training in practice will be developed. Again, the method provision tool is one of the core elements but other media will be applied as well. First, a general framework will be introduced on how the later presented concepts for training and virtual workshops are embedded into the method knowledge transfer from research to practice. Subsequently, one training concept including four in-class workshops and one online training including five virtual workshops will be described in detail. These particular training concepts will be the basis for the following evaluations in practice within chapter 8.

Figure 7-11 illustrates the framework of method knowledge transfer from research to practice. The framework is inspired by the framework proposed by Beckmann et al. (2016) and tries to address the requirements set up in chapter 5. Compared to the training concepts, the framework includes the preparation and the follow-up besides the realisation and implementation of the training. Figure 7-11 is composed as follows: the dark grey columns contain *research*, *practice* and in the centre a column for *both partners*. The light grey rows symbolise the five phases of the transfer process from *kick-off meeting*, *preparation and agreement*, *realisation and implementation*, *follow-up* to *final meeting*. The dark grey boxes with the computer symbol at one side signify an interaction or usage of the method provision tool (short *m.p.t.* in the figure). Arrows backwards or loops imply iterations whereas straight arrows mean participation of persons or provision of information or data. Actions that have to be performed use grey boxes as indicated within the explanations at the lower part of the figure.

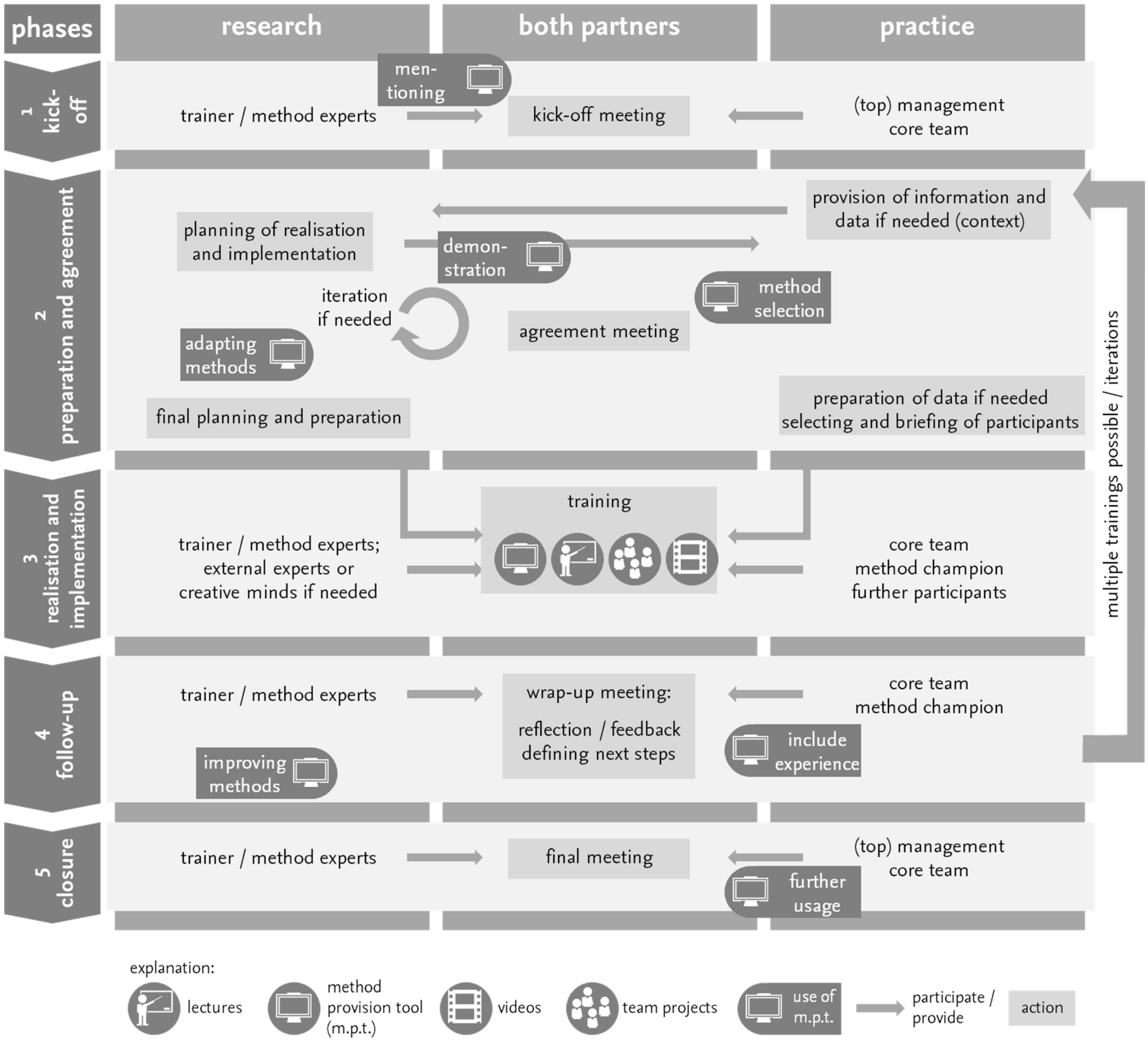


Figure 7-11 Method knowledge transfer framework from research to practice using the method provision tool

The kick-off meeting within the **first phase** serves the purpose to identify the organisation's needs and a suitable (pilot) project or task for the (first) method knowledge transfer. Preferably, the (top) management is involved to guarantee support from the beginning. The method provision tool is mentioned from research showing, for instance, a demonstration video.

The **second phase** comprises the preparation and the agreement on a final training concept. The organisation has to provide the required information on the project or task that serves as context for the transfer. The research partner conceives a first plan of the training concept, grants access to the method provision tool and demonstrates the application to the core team in the project, e.g. creating a profile. The core team uses the tool to make first method selections according to their profiles and those of further team members participating in the training. Within the agreement meeting, the final training concept is defined. Each party then prepares the corresponding elements for the training.

The subsequent **third phase**, the realisation and implementation, covers the training, which may include different media and formats depending on the content of the training and the users' needs.

Both, in the training itself and in the following wrap-up meeting in the **fourth phase**, feedback is gathered by the trainer from research. Additionally, reflection possibilities on the method applications are offered. This includes also the commentary and evaluation function of the method provision tool, e.g. useful in virtual workshops. According to the feedback, improvements on methods or method descriptions and method access can be implemented in the tool.

The phases 2 to 4 can be iterated if multiple pieces of training, e.g. a series of workshops, are planned.

At the end of the transfer process, a closure (**fifth phase**) involving the (top) management again is scheduled.

The framework tries to meet all of the general knowledge transfer requirements and those from practice. The core team can be seen as a "change team" if change processes, for instance, in the current development process are needed. The involvement or training of so-called method champions (experts on certain methods that are specially trained) is highly recommended. The framework builds the basis for the following presented training concepts in workshops and online workshops.

7.3.1 Workshop on design methods in practice

In this section, an in-class training concept fitting into the phase three of the previously presented framework is introduced. The training is universally applicable to engineering design tasks as it is based on a traditional problem-solving process from problem clarification, idea generation, detailing ideas and evaluation of ideas. Figure 7-12 illustrates such a process indicating the assignments of individual workshops (WS) as one training unit. The utilisation of the method provision tool as part of the training is demonstrated by the steps below the process in Figure 7-12.

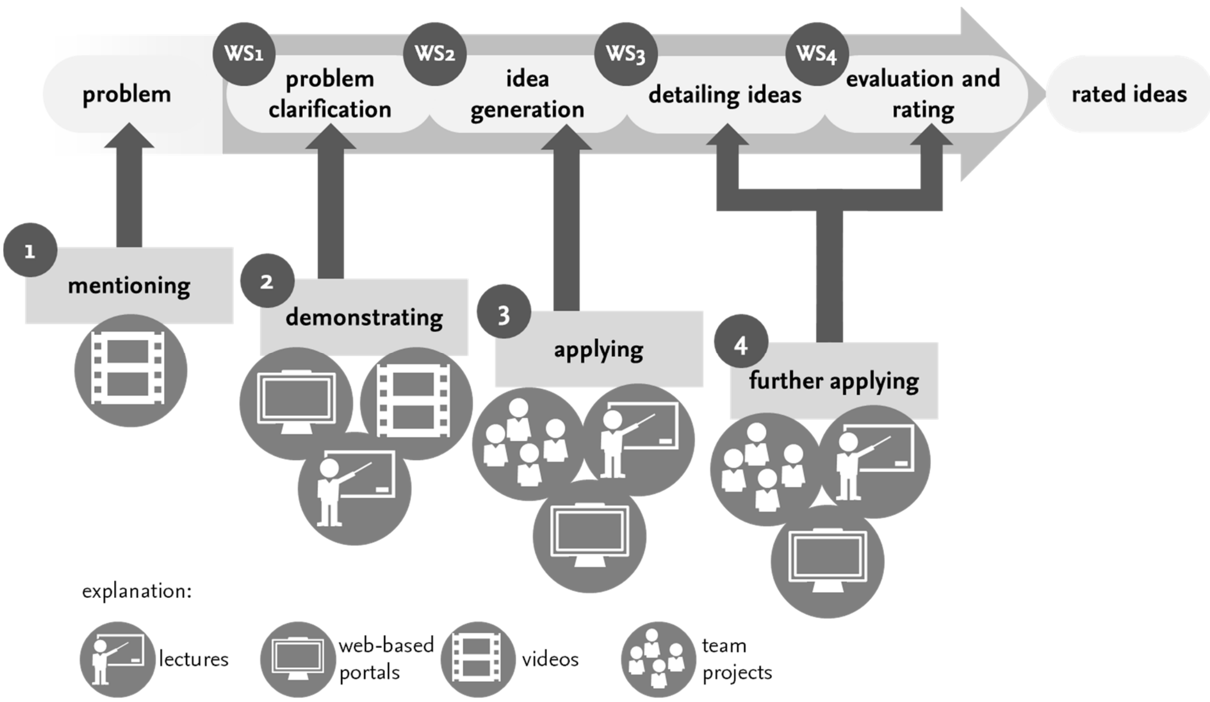


Figure 7-12 Integration of the method provision tool and other media into a transfer workshop with an company

In the preparation phase (problem), the tool is only mentioned. Within the first workshop, the tool is demonstrated and single elements, e.g. videos, of a method description are used to explain the method to be applied in the workshop. The second workshop is devised in a way that the participants have to work with the method provision tool individually prior to a method application. The method is predefined; the way of acquisition is individually selectable within the borders of the tool. Important in this step is that all participants have access to the tool within the training. Mobile devices are suitable in this context and allow flexible interactions. To provide support, questions and doubts can be discussed with the trainers. If needed, the trainers moderate the method application subsequently.

The remaining workshops are used in a similar way to the second one to deepen the work with the method provision tool as well as the understanding of different methods. The difference between the third integration step (applying) and the fourth step (further applying) is the involvement of the core team or method champion. The third and fourth workshops serve the purpose to get familiar with the method access functionalities of the method provision tool (for the core team and method champion). This means that the core team and method champion are involved in the planning of these workshops. Prior to the workshops, they select methods according to the task and their profiles as well as those of the workshop participants. During the workshop, the application of the tool for acquisition is performed as in the third step of the integration process. The trainer moderates if needed and supports the core team, method champions and all other participants. The aim is to train the core team and mainly the method expert for future method applications using the tool for acquisition.

7.3.2 Online workshop for virtual teams

As for design education, an online version of the method provision tool integration and other training media and formats was developed for practice as well. The online workshops (OW) are embedded into the framework of method knowledge transfer like the earlier presented traditional training concept. The meetings might be virtual meetings via videoconferencing, though. Due to the restrictions of technologies for the moderator(s), it is recommended to work with smaller groups (up to eight persons) as the situation might be more difficult to judge (e.g. need for pause, diverse participants). The process or topics of the training can follow the same phases as the traditional training.

In Figure 7-13, a process including also Design Thinking[5] elements like user observation and prototyping is illustrated because the virtual workshop used for the evaluation in chapter 8 was conceived like this. Thus, the training consists of five online workshops. The first workshop is used to mention the method provision tool in the beginning and to demonstrate it later in the workshop. As the tool is web-based, it is possible to demonstrate the tool via screen sharing and verbal explanations or via a video. The first method to apply is mainly presented by the moderator using the tool. The method application follows afterwards guided by the moderator. The second online workshop starts with a repetition of the functionalities of the method provision tool to ensure the succeeding method acquisition and application of a predefined method. The trainer provides support and serves as moderator during the method application. Depending on the team and the focus of the workshop, the next workshops can be used to continue with the fourth step (applying) or to proceed the fifth step (further applying) additionally including the method access via the method provision tool. If the core team equals the participating team of the online workshop, the method selection can be conducted during the workshop. Otherwise, the decision on the methods to be applied should be taken in advance to the workshops as described for the traditional training.

Important for a successful training through virtual workshops is an adequate preparation. As the moderator is not present at the individual sites of each participant, he or she has to make sure that all participants have all materials required at their disposal, e.g. paper, pencil or software. Prior to the workshop a list should be sent to all participants. Furthermore, the moderator should be experienced with method applications in virtual teams to give helpful advice on method variants for virtual teams. In addition, the moderator and preferably all participants should possess good skills with video-conferencing. Technical problems are one of the main barriers to successful method knowledge transfer in this context as the technical problems cost already much time and concentration of all participants. Finally, experiences have shown that virtual workshops require a lot of concentration com-

[5] Design Thinking is an approach for problem-solving that is mainly used in design for the creation of new products or innovative ideas. Design Thinking originates the d-School at Standford University.

pared to traditional in-class workshops. Thus, recreation in time is even more crucial for a successful transfer project (Janssen, 2017).

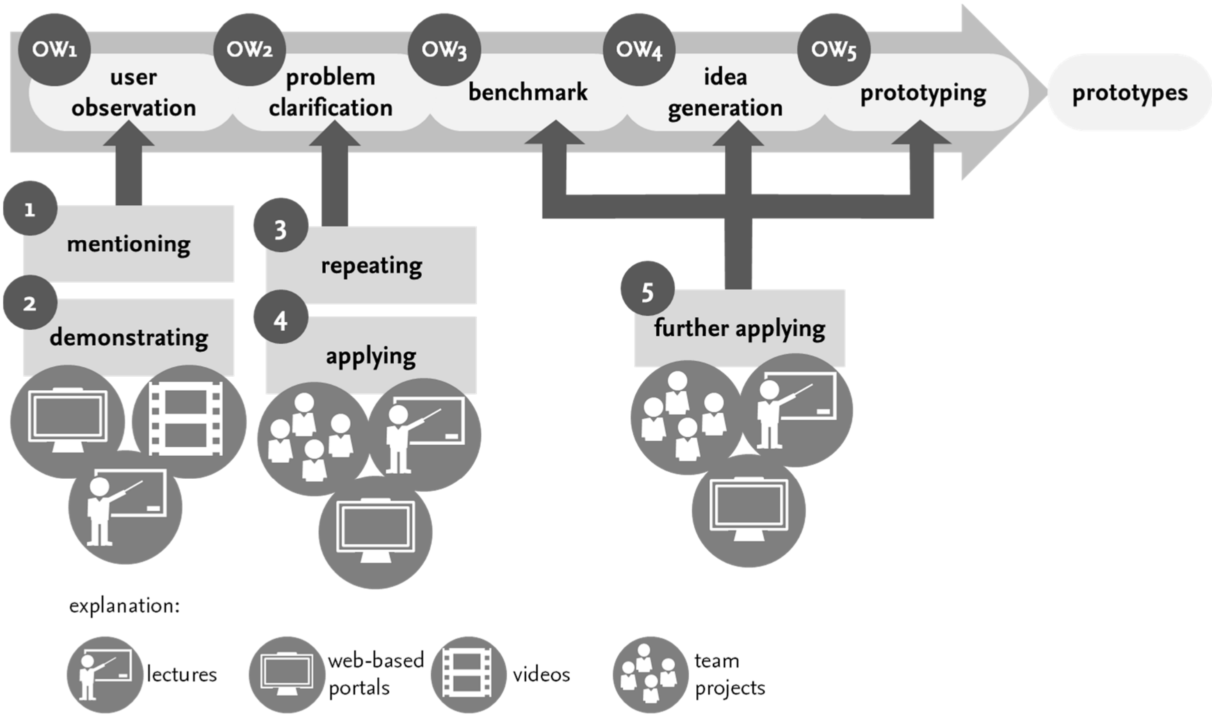


Figure 7-13 Integration of the method provision tool and other media into an online transfer workshop with multidisciplinary participants from different sites

7.4 Conclusion and reflection on research question

Building on the requirements on method knowledge transfer set up in chapter 5 and the method provision tool presented in chapter 6, this chapter answered the research question Q6 by providing training concepts for design education and practice. Therefore, general training media for engineering design methods were developed and later integrated in combination with the method provision tool into training concepts on methods. Among the media introduced, method videos, instructions on methods and software-based templates can be mentioned. The superior idea of introducing the method provision tool into design education was to provide all methods on one platform for all students independently of the semester. Subsequently, an in-class course and an online course using the method provision tool for method training were presented. In practice, a method knowledge transfer framework including preparation and follow-up measures was conceived. As one part of this framework, two particular training concepts using workshops and online workshops were described. The training concepts demonstrated serve as application for the following evaluations.

Q6 *"What are successful means for method knowledge transfer considering the target group?"*

- The consideration of the target group meaning design education and practice was done by the proposition of different concepts for each group.
- Due to the importance of practical application of methods for a successful transfer, different means supporting the fast and simple application of methods were elaborated.
- The mean for a successful transfer depends amongst other factors on the learner. There are different preferences for learning material. Thus, the provision of multiple means addresses different types of learners.
- When providing many different means, the learner should not be overtaxed. The provision collected in a method provision tool is a possible solution to overcome this problem. Thus, a combination of training and method provision tool including different means was developed.

8 Evaluation Studies

"Judge a man by his questions rather than his answers."
Voltaire, French writer

This chapter poses various questions to evaluate the results obtained in the previous chapters 6 and 7. The respondents are students or practitioners. They have tested the method provision tool in the form of the software demonstrator and further method training media to provide first results. Furthermore, they have participated in the training concepts developed (education) or in the overall transfer framework (practice). Equivalent to chapter 7, this chapter offers first general evaluation results that are independent of the target group (Section 8.1). Then extensive results from design education gathered over 1.5 years (Section 8.2) and results from smaller applications in practice (Section 8.3) will be presented. The subsequent Section 8.4 compares the results from design education and practice in certain aspects. A discussion of the evaluation results completes this chapter (Section 8.5). The structure of the chapter is illustrated in Figure 8-1. Where applicable, the evaluations are described regarding their realisation, results on the method provision and results on the method training concepts.

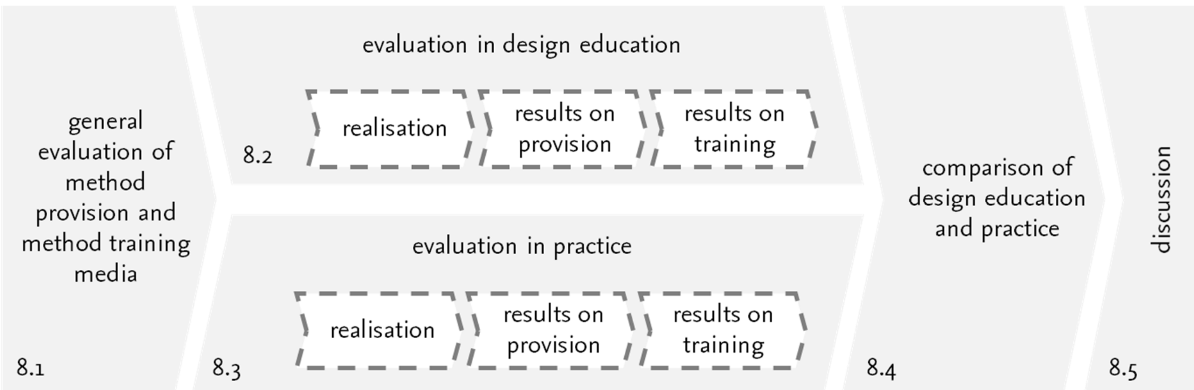


Figure 8-1 Schematic illustration of the chapter's structure

8.1 General evaluation

The general evaluation includes insights into the method provision tool's usability as well as into selected additional content for method training. These additional contents are method videos and instructions on methods. Evaluations of the three named elements will be described in the following sections.

8.1.1 Evaluation of the method provision tool's usability

Before introducing the method provision tool on a grand scale, the usability of the tool, focussing on method description and method access, as well as the introduction video and the user profile were tested.

Set-up and realisation

To do so, the observation method "think aloud" (Ericsson & Simon, 1980) and questionnaires were utilised. The think aloud method is a verbal analysis to gather information on internal information processing processes of test subjects. The idea is that the test subject expresses everything that comes to their mind when processing a certain task. This analysis method is combined with questionnaires before and after the observed task. The sequence of the usability test was chosen as follows:

1. introduction to the usability test
2. data privacy statement and first questionnaire
3. task-processing with method provision tool ("think aloud")
4. second questionnaire

The introduction includes an explanation of the usability test and its sequences. The first questionnaire contains mainly demographical data, questions on experiences with the method provision tool and with the internet's usage. Finally, the mood shall be rated for a better estimation of the later statements during the think aloud method. A short exercise on the think aloud method follows practice purposes. For the processing of the task, each test subject receives instructions in form of an exercise sheet with five tasks. The tasks comprise the following steps:

- Task 1: access the method provision tool and login
- Task 2: find out about the functionalities of the tool using the introduction video
- Task 3: access your user profile and insert the information requested
- Task 4: select a method suitable for the following situation:
  You are part of a team of five persons. You work on a design task and try to find first solution principles. You wish to come up with ideas within one hour with your team consisting only of method novices.
- Task 5: access the list of methods and select the method "Synectics"

a. find out about the *weaknesses* of the “Synectics”
b. start the *video* on the “Synectics”
c. find out about the *training effort* of the “Synectics”

While processing all these steps, the test subjects are asked to describe everything that comes to their mind. If necessary, an observer occasionally reminds them to express their thoughts. The test subject is recorded visually and aurally using camera and microphone. The screen is recorded as well. The test set-up is illustrated in Figure 8-2.

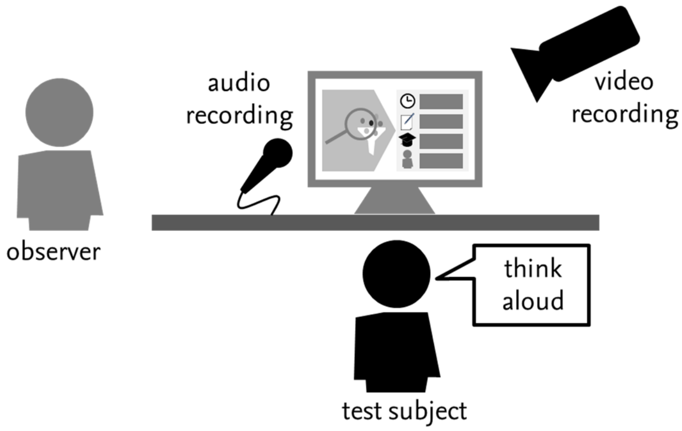


Figure 8-2 Test set-up for usability test of the method provision tool

After the usability test, a second questionnaire is handed to the test subject containing questions on the introduction video, on the method provision tool in general and on improvements.

The usability test was performed with ten participants, from seven different domains or fields of studies. The test subjects were students and research staff with different knowledge and experience levels (bachelor and master degree). This target group was chosen due to the fact that the software demonstrator METHODOS - serving for the usability test - was primary developed for students. Male and female participants were equally represented. Two of the test subjects already knew the method provision tool, but none have utilised it before. The general internet literacy of the test subjects is high to average. Internet literacy in this context means the test subjects’ ability to appropriately access the internet, communicate via internet and protect their privacy (Rau, 2017).

Results on the method provision tool's usability

The results on the usability of the method provision tool consist of two parts. First, results from the observation via the think aloud method and observer are presented. Second, results from the questionnaires complete the impression of the usability.

Figure 8-3 shows the rating of the observer regarding the accomplishment of the five tasks based on the statements made and click behaviour from the screen record. Except for the task 5a, finding out about the *weaknesses* of the "Synectics", all participants could fulfil all of the tasks. The quality of the fulfilment was rated by the German system of school grades ranging from »excellent« (1) to »unsatisfactory« (6). Most of the tasks were fulfilled excellently (task 2 to 5). Some problems occurred during login into the tool due to the missing check of accepting the privacy policy needed for the user profile or due to forgot passwords. More problems caused the method description within the tool. As mentioned, none of the test subjects could find the attribute *weaknesses*. Furthermore, only one person found out about the *training effort* of the "Synectics" without problems. Half of the participants solved this task inadequately (Rau, 2017).

Figure 8-3 Rating of the tasks' accomplishment by the observer based on Rau (2017)

The general well-processing of the tasks is supported by the results from the questionnaires. The evaluation of the operating concept of the tool, the content as well as the overall impression reveal high satisfaction with the usability of the method provision tool. The results showing the rating with school grades again from »excellent« to »unsatisfactory« are presented in Figure 8-4. Average grades range from 1.3 to 1.4 on the scale from »1« (best) to »6« (worst).

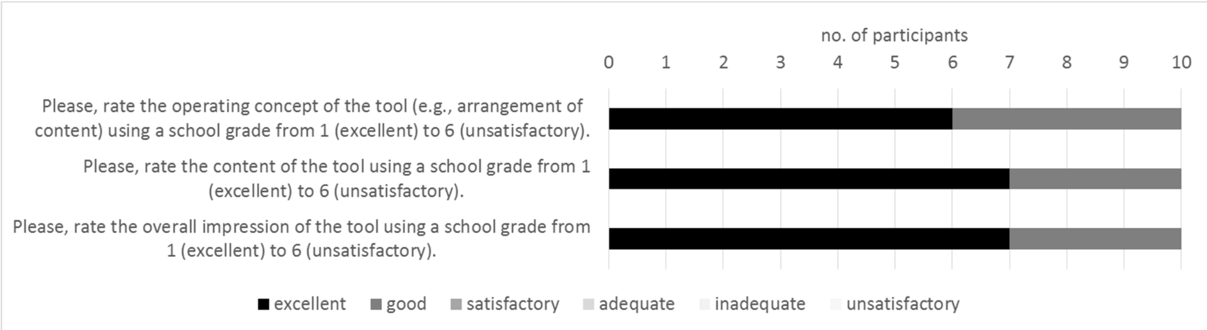


Figure 8-4 Evaluation of the overall concept of the method provision tool based on Rau (2017)

As the introduction video of the method provision tool is used to present the tool within the training concepts, the usability test focussed also on the video and its evaluation by the test subjects. As the think aloud method was not fruitful during watching the introduction video, the video was evaluated by five additional questions at the end. In general, the video was rated as helpful for the later utilisation of the tool. The explanation of the method access was also estimated as good whereas only 50 % strongly agreed on a good presentation of the method descriptions. The length of the video and the content were mainly rated as adequate. Thus, the video was found suitable for introducing the main functionalities of the method provision tool, although single improvements appeared.

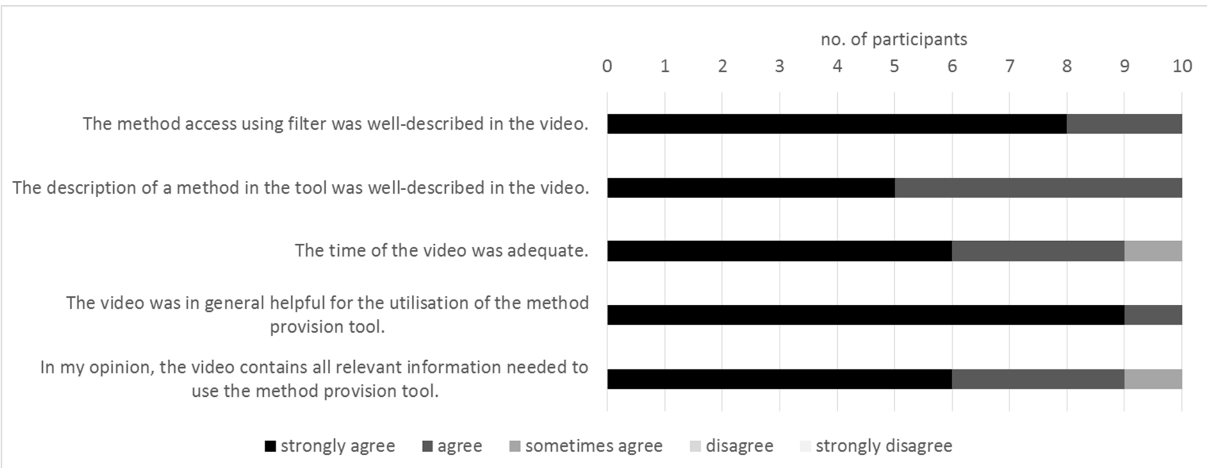


Figure 8-5 Evaluation of the introduction video based on Rau (2017)

8.1.2 Evaluation of method training media

As those of further media for method knowledge training and transfer, the method video and the instruction for methods were evaluated. The realisation of the evaluation and the results will be presented in the subsequent sections.

8.1.2.1 Method videos

Among the more than ten method videos produced and available in the method provision tool, only a few were evaluated. The method video on the Morphological Analysis was demonstrated and evaluated within a basic course on engineering design (Bachelor), the Point Rating System and the Synectics videos were introduced in an advanced Bachelor course on design methods. In a Master course on design methods, the students rated the video on the Quality Function Deployment. In context closer to practice, the FMEA video completed by the FMEA template (see chapter 7) were rated in a student group called "Lions Racing Team" developing single-seated formula racing cars for the international Formula Student cup. The video on the Weighted Point Rating System was utilised and rated within an industry workshop.

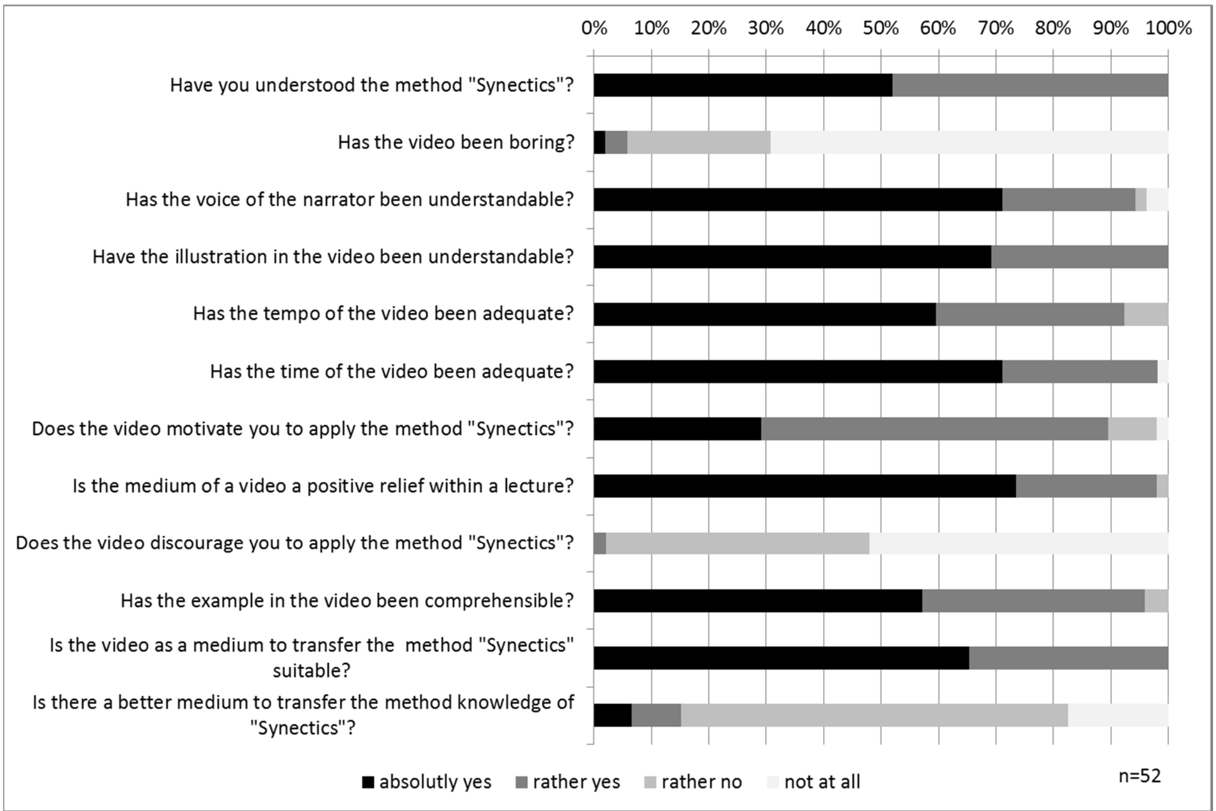


Figure 8-6 Evaluation results for the method video of the method Synectics, see also Reiss et al. (2017)

Figure 8-6 demonstrates the results of the feedback on the Synectics method as an example for the evaluation results. In this case, 52 students rated the video after a demonstration within the lecture. Besides the questions as shown below, a little quiz on the method was asked. This enables to judge the statements on questions like "Did you understand the method?” Furthermore, the medium itself as well as the realisation of the method in the form of a video were rated.

Remarkable is that the students are not completely motivated to apply the method afterwards. More than half of the students chose the method for application in the subsequent class, though. Despite the high difficulty of the method, all students claimed that they had understood or rather understood the method which could be mainly confirmed in the subsequent application. Some concerns were mentioned regarding the tempo of the video (too fast) and regarding the example which seemed to be too far from reality (development of a nut cracker). However, the overall evaluation in terms of a school grade again from »1« (best) to »6« (worst) resulted in an average grade of 1.56 (Nisse, 2016).

8.1.2.2 Instruction for methods

The instructions for methods are available in the method provision tool as additional content. They are frequently used by the students during class work but were evaluated in an industry workshop. Thus, only thirteen participants rated the instruction of the Method 635 (presented in chapter 7). The instruction was handed out together with the template. In the following, the method was applied without further detailed descriptions by the workshop moderators. At the end of the workshop, the feedback on the instruction was positive. An overall average grade of 1.62 again on a scale from »1« (best) to »6« (worst) was reached.

8.2 Evaluation in design education

Due to the high relevance of a good method education for the long-term acceptance of methods in practice, extensive evaluation studies over 1.5 years and over different courses were conducted. The aim was to check the acceptance of the concept of the method provision tool and the accompanying method training concepts among the intended target group design education. The integration of the method provision tool was accompanied by several evaluations as presented in Figure 8-7. The figure demonstrates the steps of the training concept for design education and clarifies the main purpose as well as where and when evaluations are conducted. Four samples of evaluations (A-D) will be used in the following. These samples are roughly clustered regarding the main purpose of the evaluation:

- an evaluation of the introduction (A),
- an evaluation of the general method descriptions and access (B),
- an evaluation of the describing attributes of the method descriptions (C),
- a final evaluation containing also repeating questions for comparison and questions on the training concept in total (D).

Sample A aims primary at the rating of the training concept developed in chapter 7 for education. Sample B and C focus on the method provision tool and its acceptance by the students. Sample D contains repeating questions, and thus, addresses questions on the method provision tool as well as on the training concept. However, the training concept is considered in more detail within this sample.

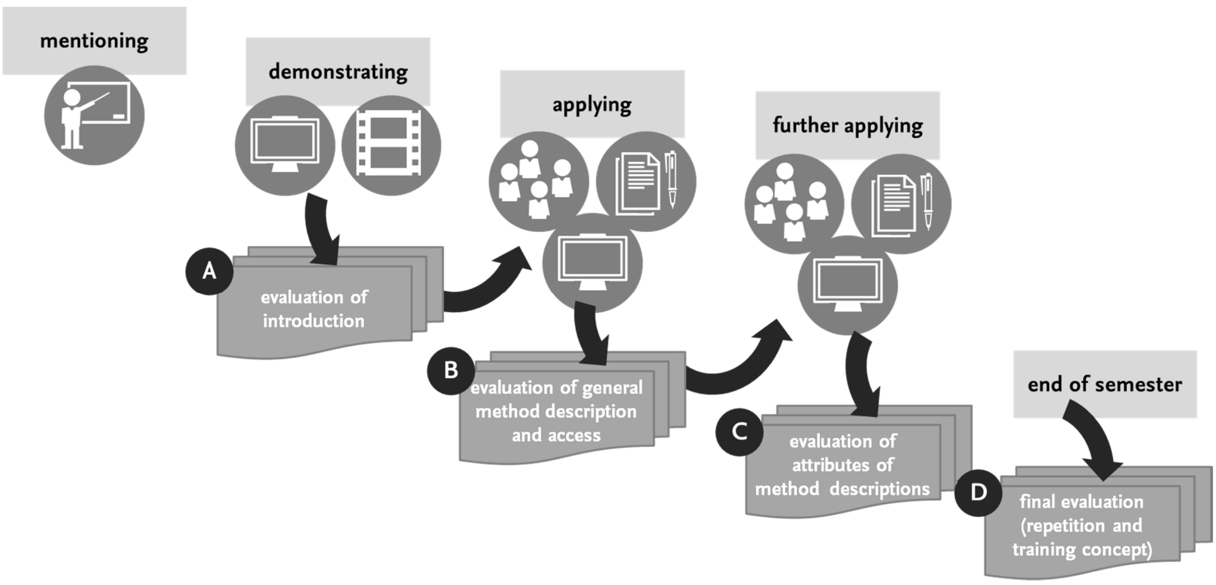


Figure 8-7 Overview of the different evaluations during the semester based on the training concept for design education

In the following, the realisation of the evaluations will be described. Subsequently, the results on the acceptance of the concept for a team-oriented method provision using the method provision tool by means of the software demonstrator METHODOS and results on the training concept will be presented.

8.2.1 Realisation

The evaluations were conducted in the basic course on systematic design and design methods (Bachelor) in winter semester 2015/2016 and 2016/2017 as well as in the more specific course on design methods (Master) in summer 2016. As the questionnaires are similar (adaptions to the practical examples etc.), those samples from evaluation A will be considered as one sample, those of B as one and so on. An overview of all samples in design education is given in Table 8-1. GPK, short for “Grundlagen der Produktentwicklung und Konstruktion”, is a Bachelor course on basics of systematic design. NMP, short for “Neue Methoden der Produktentwicklung”, comprises further knowledge on more specific design methods in a Master course.

Table 8-1 Overview of the different samples of the evaluations in design education

sample	A	B	C	D
course / level	Bachelor GPK	Bachelor GPK	Bachelor GPK, Master NMP	Bachelor GPK, Master NMP
year	2015/2016 2016/2017	2015/2016 2016/2017	2015/2016 2016/2017 2016	2016/2017 2016
size	80	64	114	89

Although the sample size is shown in the table, the sample size will be indicated in the following representation of results as there might be small differences due to unavailable answers within different stages of the evaluation. As introduced above, the letters A to D will be used for comparisons between the samples.

8.2.2 Results on method provision

This section comprises results on the evaluation of the method provision tool, on the method descriptions within the tool and on the method access. The aim is to find out about the acceptance and the applicability of the proposed concept for a method provision tool among the target group students.

Method description

A general rating of the method description within the method provision tool was requested in the middle of the semester when the tool was first applied. The rating was repeated at the end of the course. The results regarding the content of the descriptions (information needed) and regarding the clear presentation are illustrated in Figure 8-8.

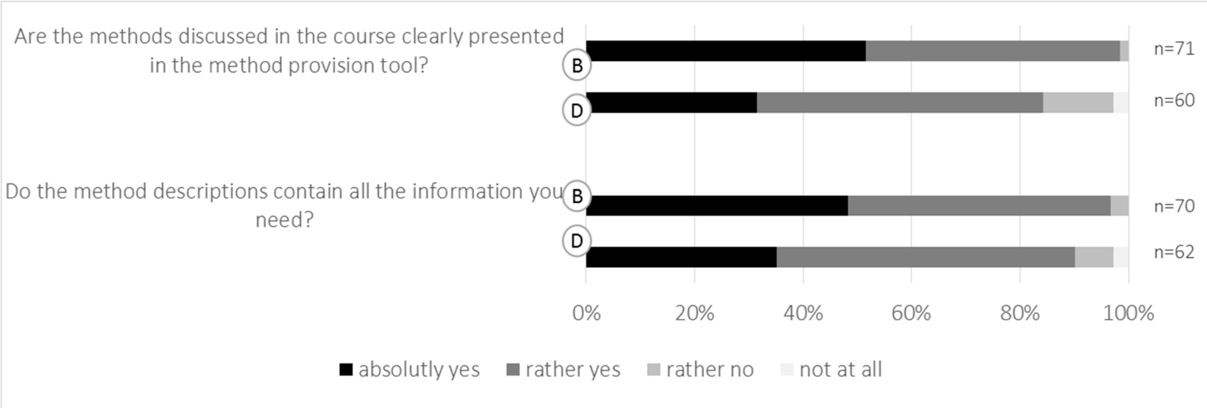


Figure 8-8 Comparison in the middle (B) and at the end (D) of the semester regarding method descriptions

Whilst at the first contact with the tool, the rating was very good (more than 90 % »yes«) for both questions, the students were more critical at the end of the semester. The results are still very good with more than 80 % »yes« answers but two »not at all« answers appeared for both questions.

To gain a more detailed view of the attributes of a method description, groups of attributes were rated in regard to their relevance, layout and comprehensibility. These evaluations were conducted directly after the application of a method which was previously acquired via the tool. The rating of the relevance of some attribute groups is presented in Figure 8-9. The criteria relevance, layout and comprehensibility were rated using a six-point scale from »excellent« (1) to »unsatisfactory« (6) according to the German school grades.

The highest relevance (most »excellent« grades) is attributed to the *procedure*, followed by the overview of the method execution on the right-hand sidebar. This attribute group provides information on the *time, training* and *preparation effort*, on the *team size*, the *materials required* and further short information. The *practical examples* also got more than 50 % »excellent« grades. The subsequent attribute groups are - with 30 % to 40 % »excellent« and many »good« grades - the *general description* with the *illustration*, the *additional tools* and the *strength and weaknesses*. The team-oriented attributes (*information on team* regarding virtual teams and *method experience*) were rated with 10 % to 20 % »excellent« and up to 30 % »good« results.

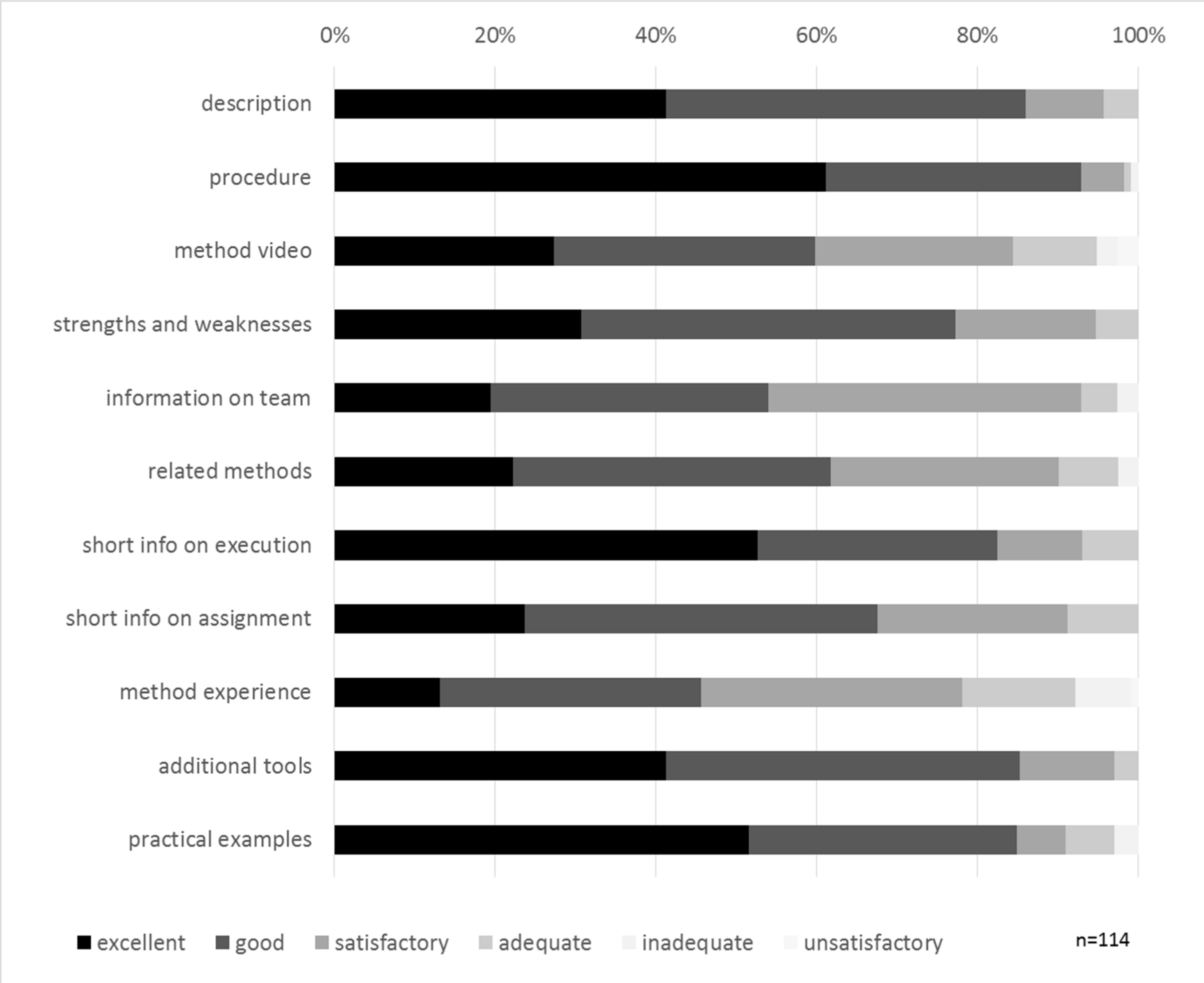


Figure 8-9 Evaluation of the relevance of selected groups of attributes (C)

Method access

Regarding the method access, more than 80 % of the students confirmed at the end of the semester that it was easy to work with the filter options and that the filter options were suitable for method access. Only two students out of 89 were »not at all« familiar with the method access.

Having a closer look at the results, the *team size* was best rated for method access criteria of all proposed criteria (see Figure 8-10). Subsequently, the *required time effort* and the *aim of the method usage* were rated as important. The lowest acceptance of access criteria got the *method classification*. All together, all access criteria were evaluated rather important than not.

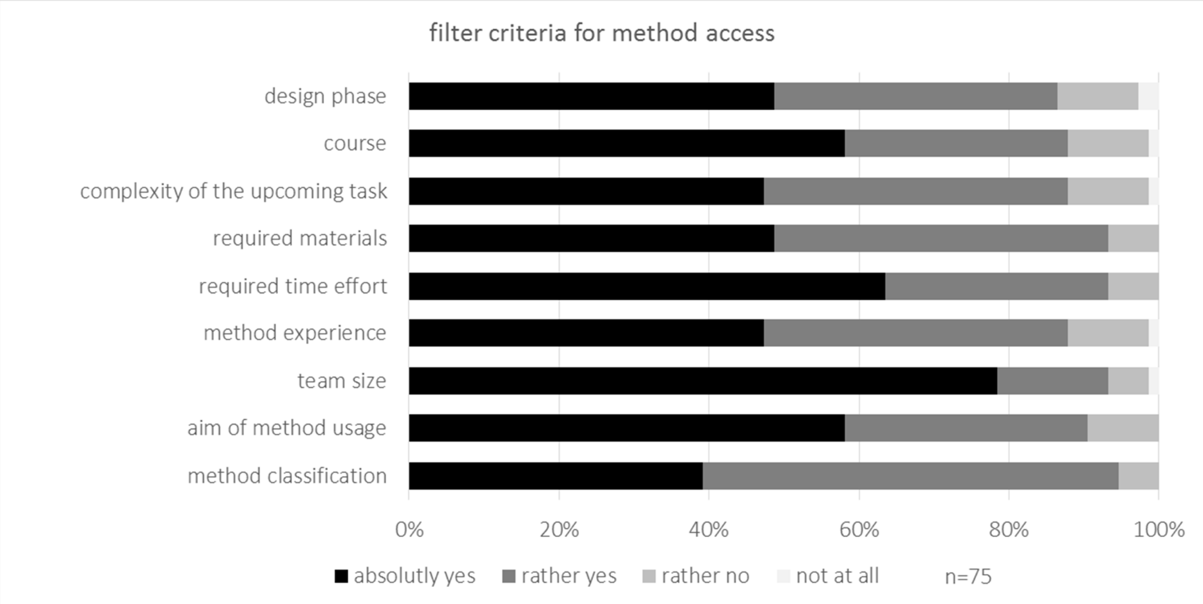


Figure 8-10 Comprehensibility of access attributes at the end of the semester (D)

General rating of the method provision tool

Finally, to asses the overall impression of the method provision tool, another rating was requested with school grades from »excellent« (1) to »unsatisfactory« (6). The results comparing the middle to the end of the semester are represented in Figure 8-11. It is noticeable that in terms of percentage more »excellent« grades were awarded at the end of the semester than in the middle. Yet, the number of »good« grades decreased and some »adequate« ratings came up compared to the rating in the middle of the semester. However, the ratings are quite similar and overall positive, for that reason the method provision tool is assumed to be »good« (average rating as school grade is 2.03 both at the end and in the middle of the semester).

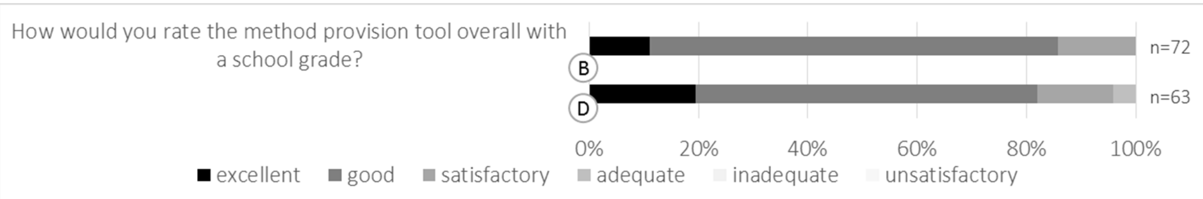


Figure 8-11 Comparison of an overall rating of the method provision tool with school grades in the middle (B) and at the end of the semester (D)

8.2.3 Results on the concept for training design methods

Beside the evaluation of the proposed concept for method provision, the concept for training design methods in design education shall also be evaluated by the corresponding target group regarding the quality and the usefulness. In this context, the overall usage of the method provision tool for method training, the introduction within the demonstrating phase as well as ratings after the applying phase are presented.

For a successful training concept, it is important that the training aim is obvious for the students. Thus, they were asked whether the connection between method provision tool and topics within the course were clear. More than 40 % affirmed the clear connection and another 40 % saw at least a rather clear connection (see Figure 8-12). Furthermore, about 70 % of the students estimated the integration of the tool as helpful or rather helpful. These findings support the success of the integration. This is why in the following semesters the integration was deepened and broadened to further courses.

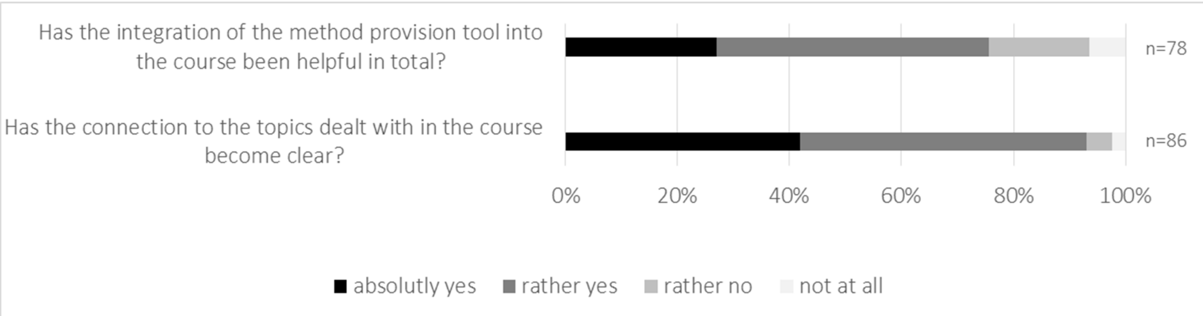


Figure 8-12 Rating of the general integration of the method provision tool into the course at the end (D)

Beside the general integration, the way how the method provision tool was introduced in the courses was evaluated. As described in chapter 7 (see also Figure 8-7), four steps are used for the introduction: mentioning, demonstrating, applying and further applying. The mentioning step was only evaluated by the question if the tool was known before. In the beginning, only 15 % knew the tool in sample A. Thus, the mentioning phase is improveable. In contrast, the demonstrating step evaluated in sample A (directly after the introduction) and at the end of the semester in sample D was rated highly. Both at the beginning and in the end, the evaluation results are good (up to 50 %) or rather good. Only a few students did not like the introduction at all. The results of three questions regarding the demonstration are illustrated in Figure 8-13. The questions aim at the easy and clear explanation of the method provision tool, the information on the usage and the presented introduction video.

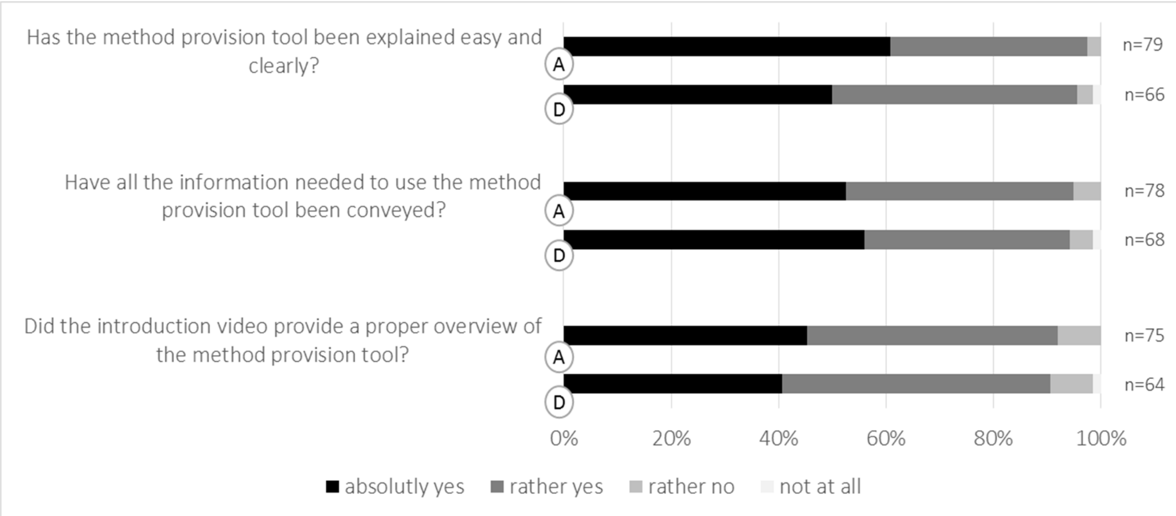


Figure 8-13 Evaluation of the introduction of the method provision tool within the demonstrating phase at the start (A) and at the end of the semester (D)

After a successful demonstration step, the applying step was rated by the students after the first application of the method provision tool in connection with a method application on a simple design task (sample B). The information needed to work with the tool was familiar for almost everyone (see Figure 8-14, first graph). The helpfullness was recognized (up to 80 %) but only by around 20 % rated with »absolutely yes«. Here an even better linkage of tool and task has to be conceived.

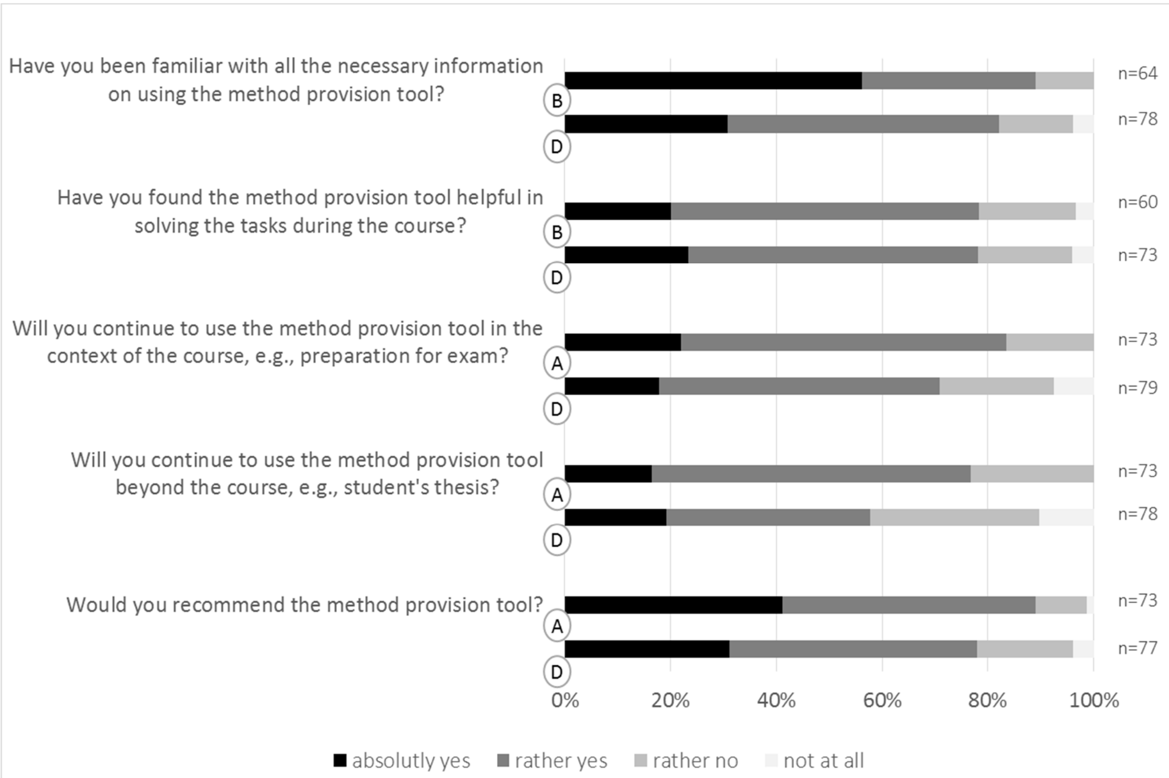


Figure 8-14 Rating of the integration of the method provision tool and further usage at different stages in the semester

Regarding further application possibilities of the method provision tool, most of the students will use or rather use the tool for exam preparation and around the same percentage for student's thesis or project work. Interestingly, the relevance for using the tool decreased closer to the exam date at the end of the semester (sample D) compared to sample A. Finally, around 80 % of the students would recommend the method provision tool both at the beginning and at the end of the semester. The percentage is slightly higher in the beginning. The integration of the method provision tool into the courses seemed to be successful although single elements like the connection to an exemplary task can be improved.

8.3 Evaluation in practice

The method provision tool and its application within training concepts has been tested within some workshops with practitioners. In this section, evaluation results from a traditional local workshop as presented in Section 7.3.1 and of a virtual workshop as presented in 7.3.2 will be described. Comparable to design education, the aim of the evaluations was again to test the proposed concepts on the method provision as well as on the method training among the corresponding target group made up of practitioners. So, the aim was not to evaluate the usefulness and the impact of the method provision tool or the training within the companies. The focus is on the usability of the method provision tool in the form of the software demonstrator and on the quality of the training concept in the form of a series of workshops. The sample sizes are considerably smaller than in design education.

8.3.1 Local team workshop

The training concept with traditional workshops was applied at an industry partner for finding new product ideas. There was an evaluation conducted after each of the four workshops. The first evaluation focussed mainly on the introduction. The second evaluation repeated some questions on the evaluation. Additionally, the method descriptions in the method provision tool were addressed. In evaluation 3, the method access was rated, whereas the last evaluation focussed on the training concept over all workshops. The training concept in connection to the evaluations is illustrated in Figure 8-15.

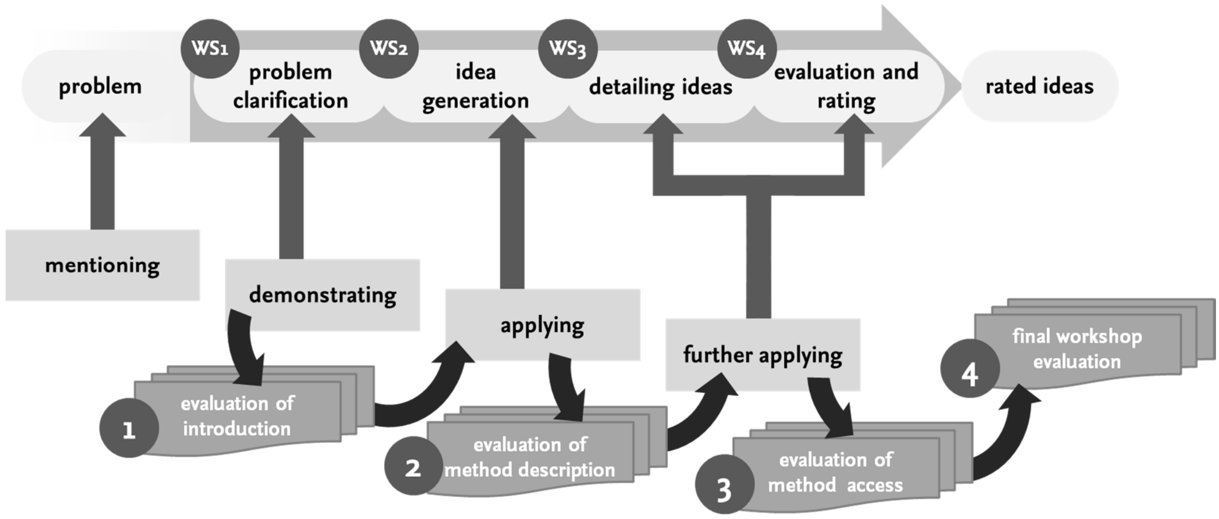


Figure 8-15 Focus and time of evaluations within the local training concept

8.3.1.1 Realisation

The participants of the workshops changed from one workshop to another except for the core team. The core team consisted of five persons who were mostly present in each workshop. The last workshop for evaluating the ideas took place with only the core team present. Thus, the sample sizes vary from one evaluation to another. Hence, the sample size will be indicated in each figure as in some questions only the core team answered.

8.3.1.2 Results on method provision

Like the results for design education, the following evaluation results are clustered into results on method description, method access and a general evaluation of the method provision tool.

Method description

After the first self-application of the method provision tool in workshop 2, the participants were asked about their opinion on the presentation and content of the method descriptions. Most participants evaluated the presentation good or rather good, whereas the content was slightly worse rated but still rather well (see Figure 8-16). Additionally, 70 % of the participants liked to have more information on the team and its characteristics. Although some information on the team and its experiences are provided, most participants require more information like those proposed in chapter 6.

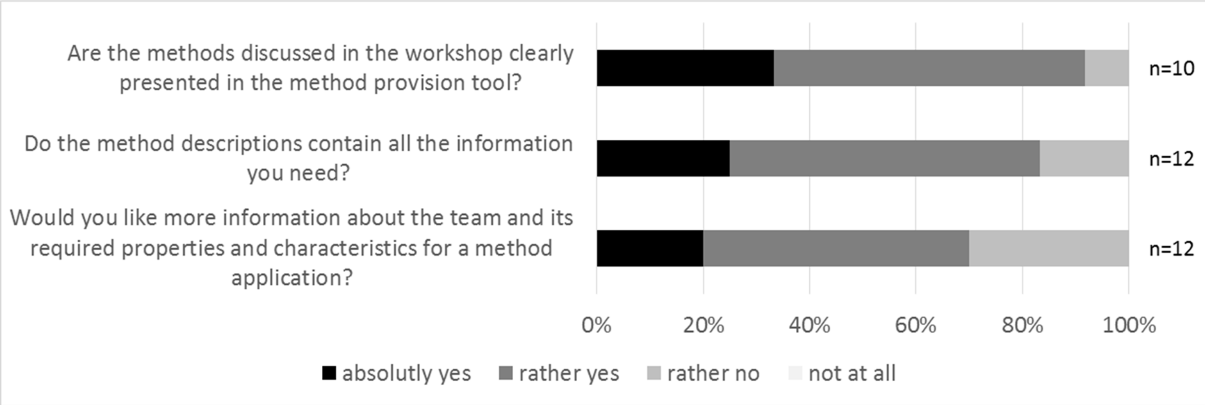


Figure 8-16 General evaluation of method descriptions in the method provision tool in workshop 2

To gain more information on single elements and attribute groups of the method description, the relevance, layout and comprehensibility of these elements were rated. Figure 8-17 gives an overview of the ratings of the relevance. The scale used is again German school grades from »excellent« (1) to »unsatisfactory« (6).

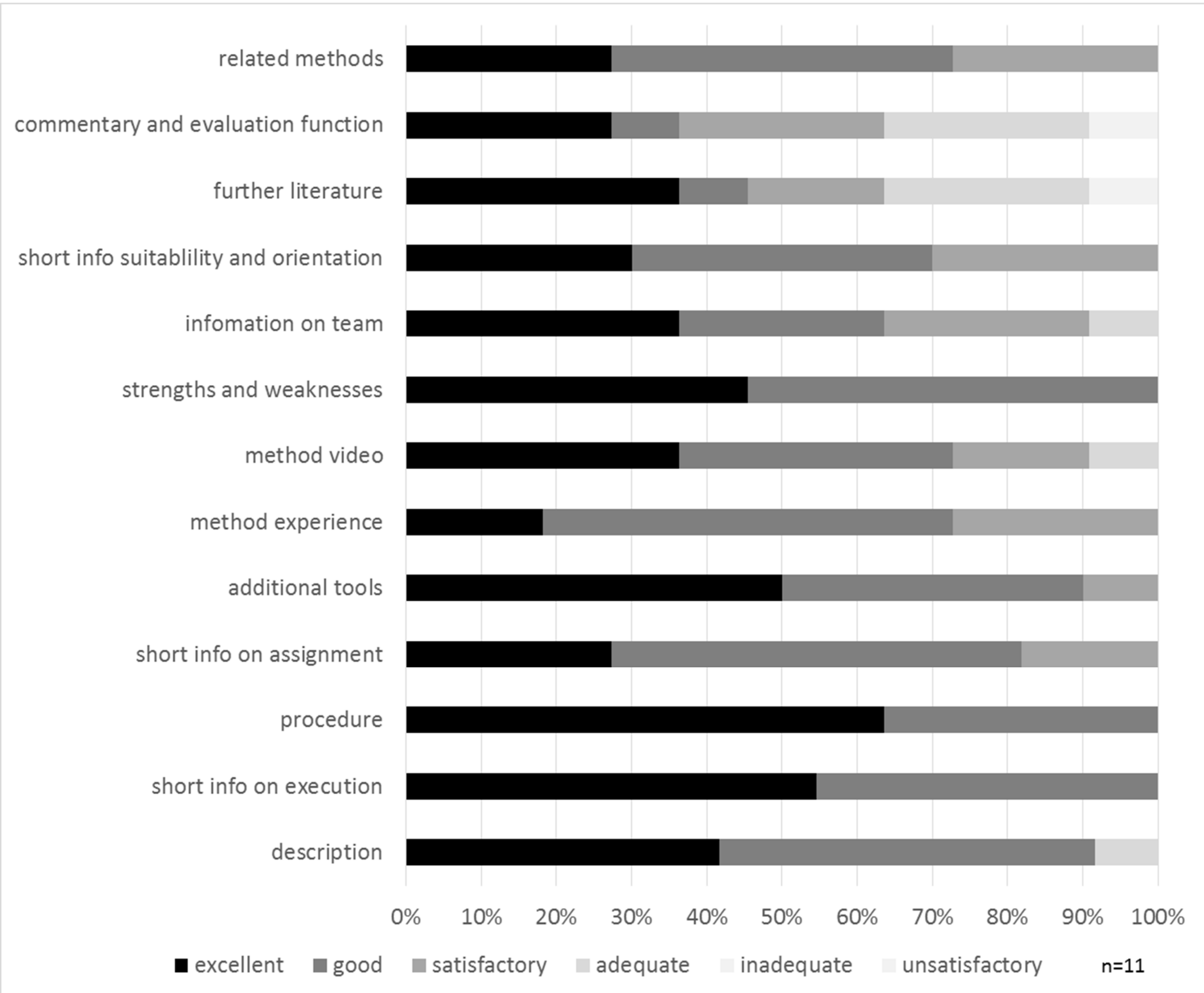


Figure 8-17 Evaluation of the relevance of selected groups of attributes (workshop 2)

The attributes or attribute groups most relevant according to this sample are the *procedure* and the short information on the method execution on the right-hand sidebar (only »excellent« and »good«). *Additional tools*, *description* and *strength and weaknesses* are similarly rated high, whereas the later-named only received »excellent« and »good« grades. The lowest percentage of »excellent« grades got the *method experience* but there is a high number of »good« grades. *Further literature* and the *commentary and evaluation function* were rated with »unsatisfactory« once.

Method access

As the method selection for the workshops took place in the core team and with the moderators, a portion of the workshop participants did not utilise the method access themselves. Thus, the core team answered questions regarding the relevance of the existing filter options and the other participants were asked to rate the relevance of the proposed filter options hypothetically without knowing them in detail.

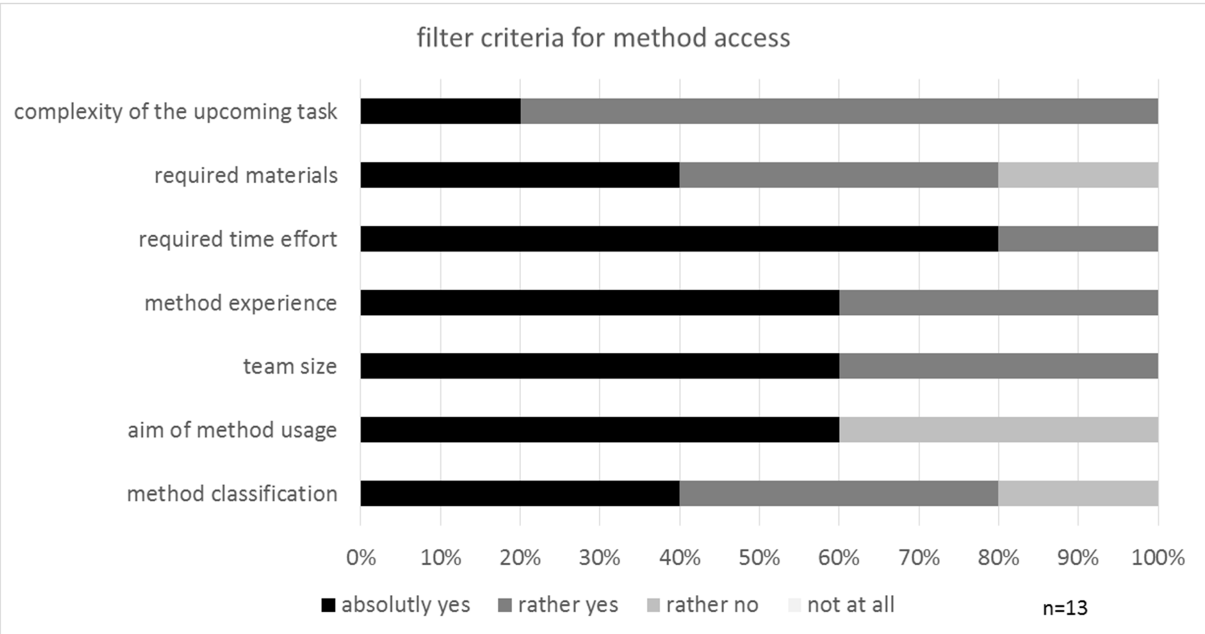


Figure 8-18 Relevance of access attributes in workshop 3

Due to the similarity of the results, they are presented combined in Figure 8-18 without differentiation between core team and other participants. The best-rated filter is the *method classification* (more than 90 % »yes« or »rather yes«) followed by the *required time effort* (about 80 %) and the *aim of the method usage* (below 70 %). The lowest relevance is awarded to the *required materials* (below 50 %) and the *method experience* (60 %). Remarkable is that the *complexity of the upcoming task* is evaluated with only 15 % »yes«, but a high number of »rather yes«. Also noticeable is the complete positive rating of the *team size*. There are no negative answers regarding the relevance which underlines the importance of considering the team in method provision.

General rating of the method provision tool

An overall rating of the method provision tool was requested at the end of each workshop. The results in comparison are presented in Figure 8-19. In general, the majority for the grades are »good« grades. In workshop 2 and 3 some »satisfactory« results appeared. The average rating is, thus, between 2.0 and 2.3.

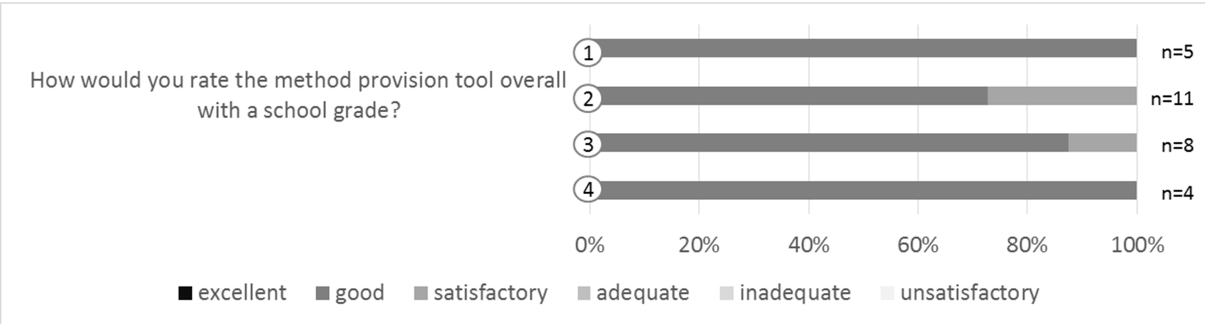


Figure 8-19 Comparison of an overall rating of the method provision tool with school grades in each workshop (1-4)

The comparison of the impression of the core team on the method provision tool mirror similar results. Figure 8-20 shows the ratings of the overall impression of the method provision tool on a scale from »0« (worst) to »10« (best) made by the members of the core team after each workshop. From a more positive impression in workshop 1, the rating decreases to a neutral view on the tool in the second workshop and rises again or stays constant in the later workshops.

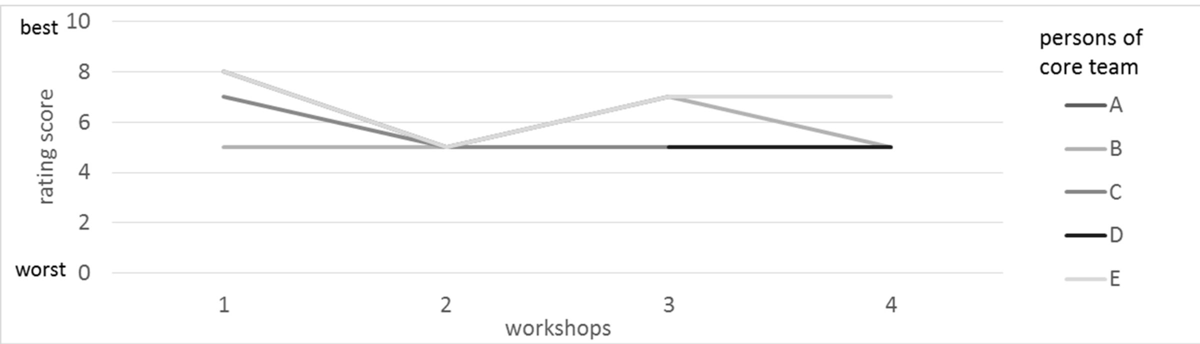


Figure 8-20 Rating of the overall impression of the method provision tool over the sequence of workshops per person of the core team

8.3.1.3 Results on workshop concept

To get a better impression on the satisfaction of the workshop participants with the training concept and to integrate feedback into the next workshops, some basic questions on the workshop and its contents were asked. An overview of the results of these questions over all workshops is given in Figure 8-21. One can observe that all questions of workshop 2 were rated slightly worse than those of the other workshops. The explanation is seen in different understanding of the workshop contents between the core team and the moderators. Thus, the expectations were not met. Additionally, some of the methods chosen by the moderators had a low acceptance due to the fact that the workshop participants used to apply these methods, e.g. Gallery Method, in another context and did not recognise the suitability for the underlying task. The solution for the next workshop to involve the core team even more in the decision on the methods to be applied within the workshop worked out quite well. This is confirmed by the positive results of almost all questions in workshop 3 and 4. These experiences highlight again the importance of the requirements for method knowledge transfer to involve the people in the decision on methods.

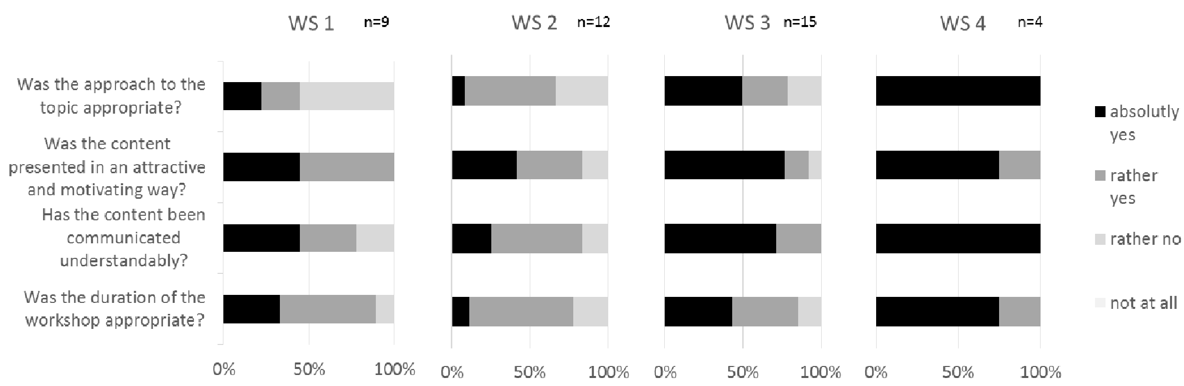


Figure 8-21 Comparison of all workshops regarding the training concept within each workshop

Focussing more on the method provision tool and its integration into the training concept, Figure 8-22 illustrates the summarised results of the helpfulness of the integration and the connection to the topics of the workshops. The ratings of all workshops are combined within one bar for both questions to demonstrate the overall opinion. Only about 50 % of the participants estimated the integration as helpful or rather helpful. The topical connection was seen by 80 % but only about 10 % said »absolutely yes«. These results can be explained with the low integration of the method provision tool compared to the design education course. The core team mainly used the tool outside the workshop. The tool was only consulted by all participants for method descriptions. Though, most of them indicated to have had preferred a verbal presentation or slides instead of a self-study. Accordingly, the core team was more involved in the preparation in using the tool compared to the rest of the workshop participants.

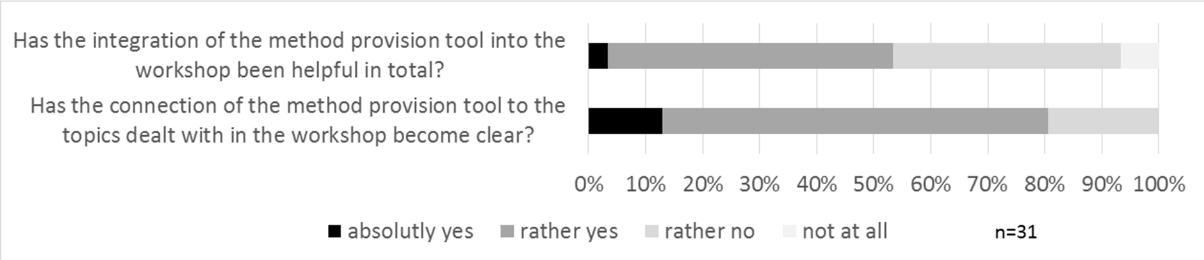


Figure 8-22 Rating of the general integration of the method provision tool into the training concept over all workshops

However, the introduction of the method provision tool within the first and second workshop was mostly appreciated by all participants. Only 10 % of the participants of workshop 2 gave negative answers to the introduction questions (see Figure 8-23). About 50 % of workshop 1 and 2 said »absolutely yes« regarding the questions on the clear explanation, the provision of needed information and the suitability of the introduction video. The easy and clear explanation of the method provision tool in workshop 2 was rated worse compared to the other questions. This may have been caused by the fact that some of the participants knew the tool from workshop 1 and other, being new to the team, did not.

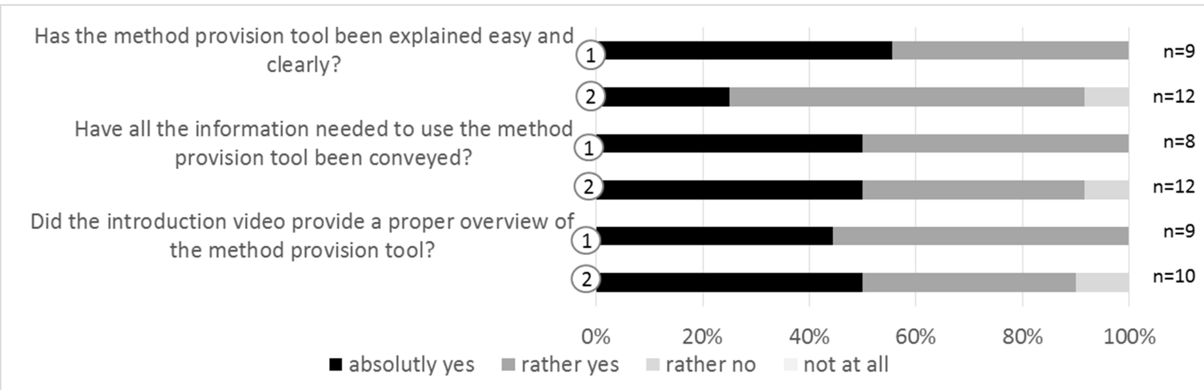


Figure 8-23 Comparison of workshop 1 and 2 of the evaluation of the introduction of the method provision tool within the demonstrating phase

Despite the relatively bad rating of the helpfulness of the integration of the method provision tool into the training concept, the recommendation and further usage were mainly positively evaluated over all workshops. Figure 8-24 presents the results of the questions concerning the applying step of the integration process (familiarity with the usage of the tool and further usage perspectives) combined from all workshops. About 80 % to 90 % would like to use the tool after the workshop for acquiring methods and they would also recommend the tool to colleagues.

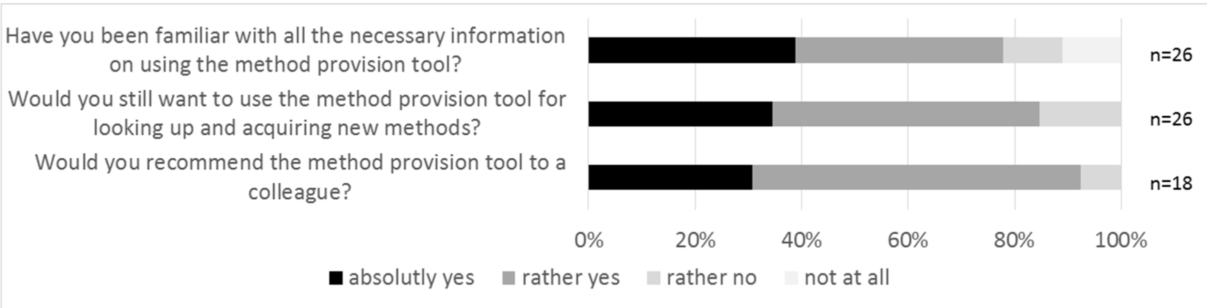


Figure 8-24 Rating of the integration of the method provision tool and further usage as average over all workshops

8.3.2 Virtual team workshop

One virtual training concept for practice could be evaluated within a row of five online workshops. The training concept as described in chapter 7 is illustrated in Figure 8-25 supplemented by the times of evaluation. The questions regarding the usage of the method provision tool were repeated during each evaluation to track the opinions over time.

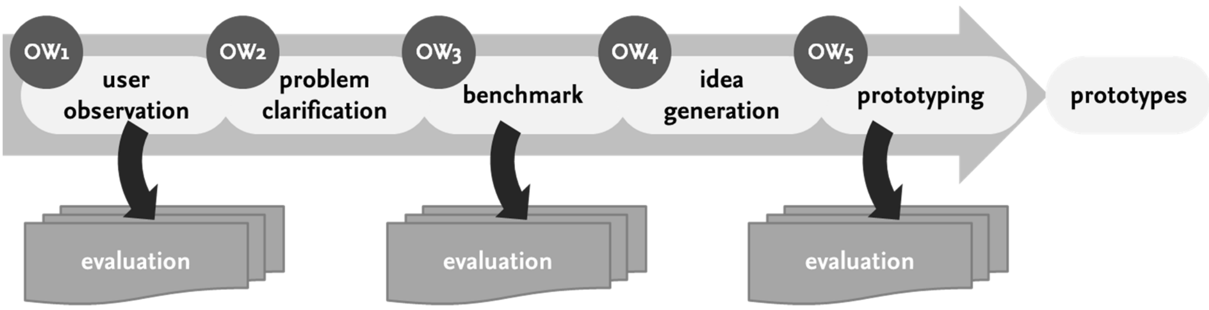


Figure 8-25 Repeating evaluations after online workshop (OW) 1, 3 and 5 using the same questions

8.3.2.1 Realisation

The five online workshops took place over a time of about three weeks. Between the first and the second as well as between the fourth and the fifth workshop a bigger pause was planned. The first pause was conceived to prepare bigger adaptions if needed. The second pause was used to prepare the prototyping workshop and to send the required material to all participants. There were only four participants but always the same persons. The participants are evenly distributed engineers and industrial designers. As environment for the online workshops, the software tool TeamViewer (TeamViewer GmbH, 2005) was utilised. Most of the participants had experiences with TeamViewer. None of them had known the method provision tool before (Janssen, 2017).

8.3.2.2 Results on method provision

The results of the method provision are summarised in Figure 8-26. Each block of results belongs to one workshop (1, 3 and 5) answering the same questions (on the left-hand side). In general, the results become better over time. Especially the satisfaction with the method results as well as the explanation and presentation of methods were rated better in the third and fifth workshop compared to the first one. The content and the way of describing the methods in the method provision tool were rated quite good in the fifth online workshop, whereas in the first workshop these aspects were average only.

The moderation of the online workshops showed that some practice with the method provision tool is required to acquire the relevant information. Once the tool and its operating are understood, the ratings improve.

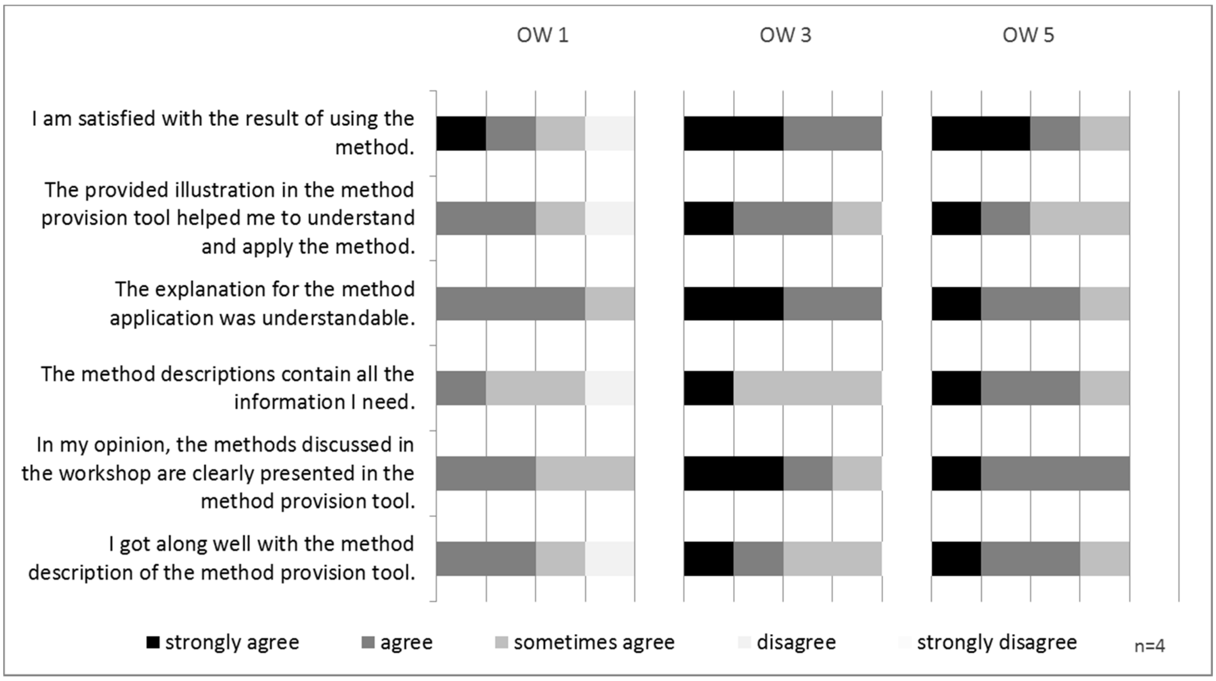


Figure 8-26 Evaluation of the method description and introduction with the help of the method provision tool within the online workshops (OW)

8.3.2.3 Results on workshop concept

The online workshops were rated in total afterwards. The corresponding results of the general sequence of the workshops are demonstrated in Figure 8-27. The participants were more content with the later workshops compared to the first.

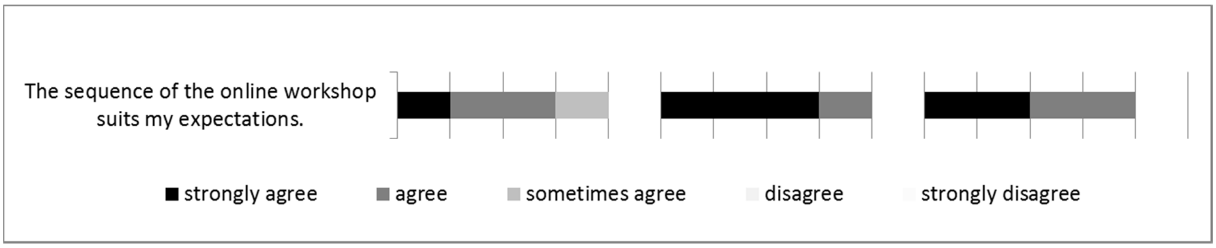


Figure 8-27 Results on the single online workshops (OW) and their sequence in total based on Janssen (2017)

An explanation for this result might be on the one hand the increasing practice with the method provision tool. On the other hand, the participants had more technical problems within the first workshops with sharing their method results, with presenting via the TeamViewer program and with concentrating on the workshop without being physically in one room. The later workshops have gone better concerning the usage of the technologies. Thus, a better focussing on the workshop contents might have been possible.

8.4 Comparison of design education and practice

This section compares the evaluation results previously presented of design education and practice to gain insights in the differences of the target groups. Note that the sample size in design education is clearly higher than in practice. Though, some interesting findings in the form of differences between the two target groups will become apparent. First, results on the method provision, including method description, method access and the overall rating of the method provision tool, will be described. Then, results on the method training concepts will be compared.

8.4.1 Results on method provision

Starting again with the method description in general, the comparison of design education (DE) and practice (P) reveal no large differences. Figure 8-28 compares the results from practice to those from design education for a clear presentation and for the information contained in the descriptions. Both questions were slightly better rated by the students, especially when answering »absolutely yes«.

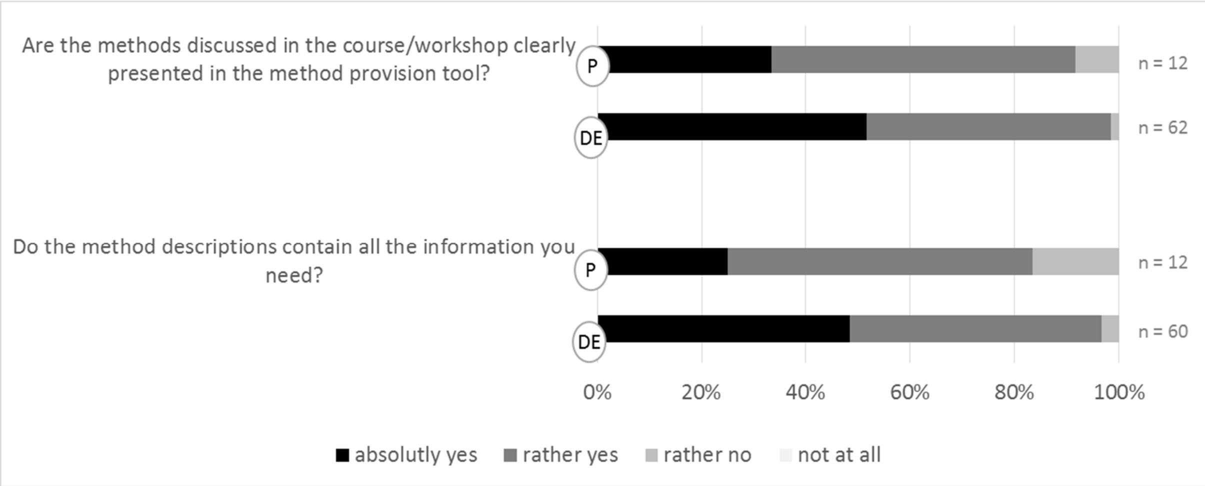


Figure 8-28 Comparison of a general evaluation of method descriptions in design education (DE) and practice (P)

Concerning the relevance of single attributes or attribute groups within the method description, the mean of the school grades (»1« best, »6« worst) given in design education and of the one in practice were calculated for each element. The comparison of the means over these elements is illustrated in Figure 8-29. It is remarkable that the means of both target groups follow a similar trend meaning that the relevance was rated similarly in relation to other elements. Except for the *description*, all other elements were rated less relevant (worse average school grades) in design education.

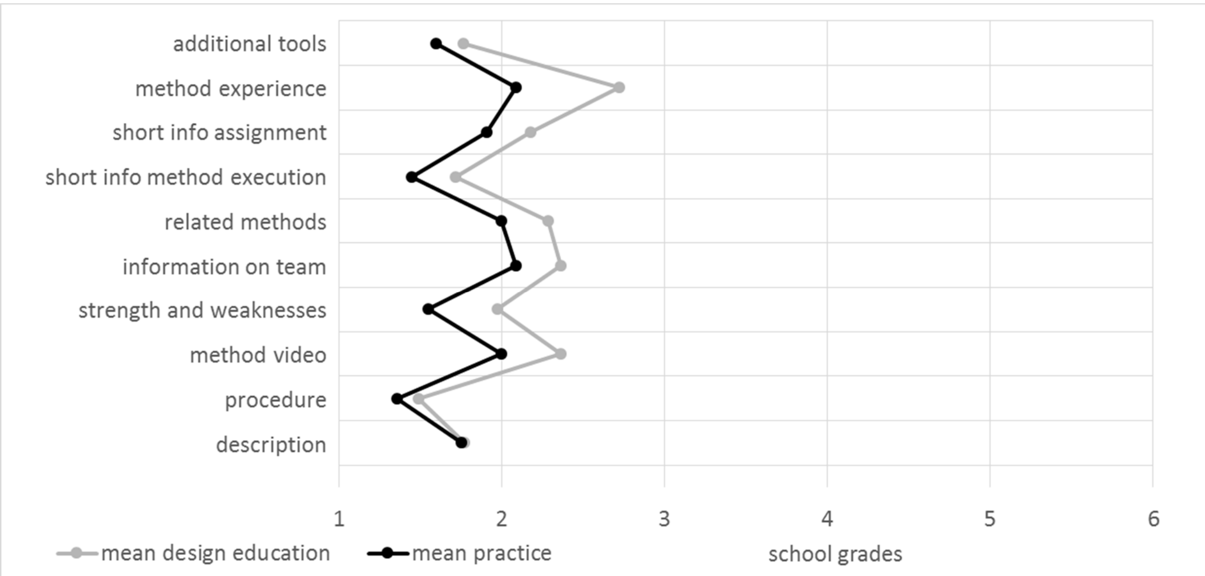


Figure 8-29 Comparison of the relevance of elements in a method description in design education and practice as average school grade (»1« best, »6« worst)

As a result, it can be noted that the attributes for describing a method have similar relevance in both design education and practice. The differentiation between both target groups regarding the method description makes less sense than assumed. Thus, a potential solution could be a common basis for method descriptions with the possibility to adapt single describing attributes.

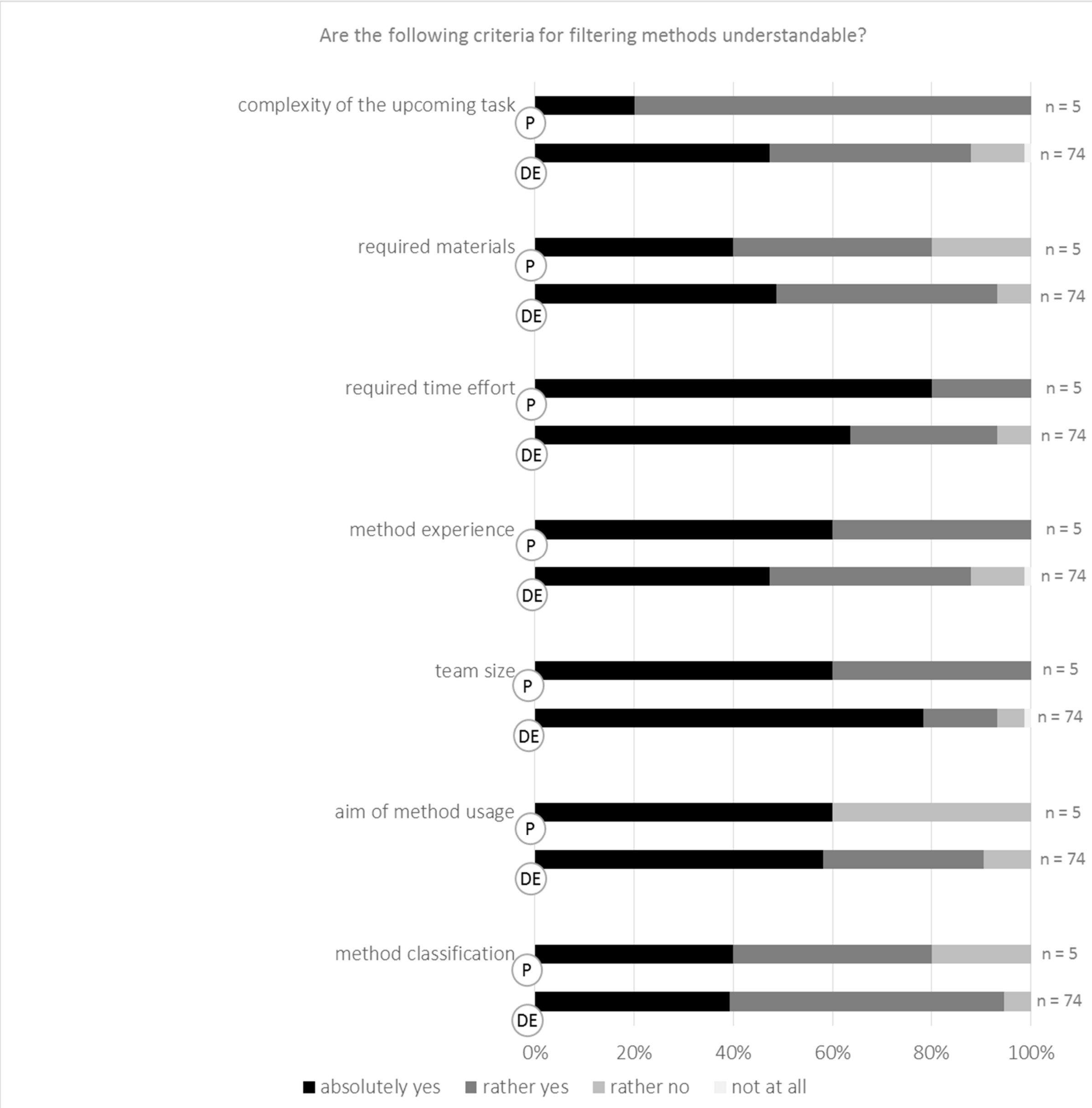


Figure 8-30 Comparison of the comprehensibility of selected access attributes in design education (DE) and practice (P)

The comparison of method access, as presented in Figure 8-30, shows that the comprehensibility of selected access attributes like it was estimated in practice (P) coincides in most aspects with the rating of the students in design education (DE). Some differences appear for instance considering the *aim of the method usage* which might be explained by the different sizes of the samples and the low sample size in practice: the results in practice are split up in »absolutely yes« and »rather no« answers. Thus, 40 % (being 2 persons) compared to 10 % (being 7 persons) of the students do rather not understand this access attribute. Hence, the tendency of the ratings is similar but not meaningful.

Finally for the method provision, the overall rating of the method provision tool with school grades is compared. The results showing the sums of all estimations given in the samples are presented in Figure 8-31. Remarkable is the better rating of the students due to given »excellent« grades. In practice no »excellent« was given but in constrast no »adequate« or worse either. The average school grade for practice is 2.14, in contrast to 2.03 in design education. As a conclusion, one could assume the existing software demonstrator of the method provision tool to be better suiting for the target group design education than to practice. This result is not surprising in view of the fact that the demonstrator was developed for education.

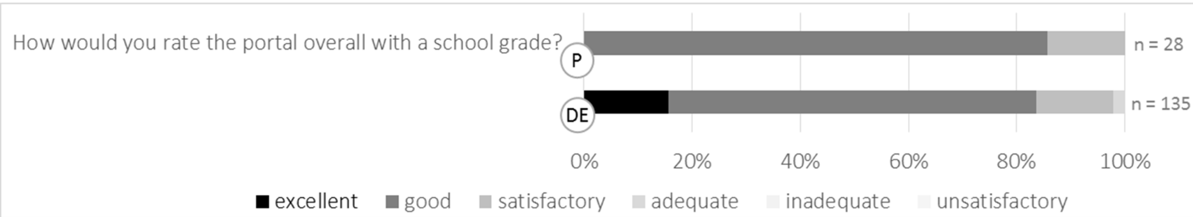


Figure 8-31 Comparison of an overall rating of the method provision tool with school grades in design education (DE) and practice (P)

8.4.2 Results on training concepts

As the training concepts for education and practice differ, this section only compares the integration of the method provision tool in general and the further usage of the tool.

The helpfulness of the integration as well as the connection to the topic of the course or the workshop were better rated in design education than in practice (see Figure 8-32). Whilst the topical connection was mainly positively rated in both samples (80 % in practice and about 90 % in education), only about 50 % in practice found the integration helpful in the workshop. The students evaluated the integration with 75 % mainly positively. As mentioned previously, an explanation for the low acceptance of the integration can be seen in the expectations of the workshop participants who rather like to use the tool outside the workshop for preparation or further training. In the context of a workshop, the acceptance to take responsibility for the own learning outcome was quite low. The participants preferred presentations similar to ex-cathedra teaching to working on their own to acquire a new method. In contrast, the students in design education seemed to be more motivated to work on their own and to decide on how to acquire the knowledge during the course.

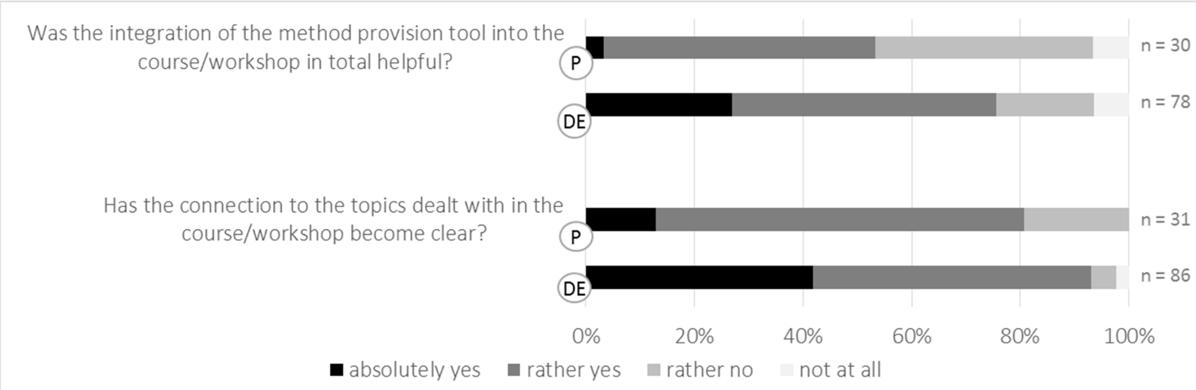


Figure 8-32 Comparison of the general integration of the method provision tool into the training concept in design education (DE) and practice (P)

Outside the course or the workshop, the impressions change: the willingness to further work with the method provision tool is quite high in practice (more than 80 %), whereas more than 30 % of the students indicate (rather) not to use the tool again (see Figure 8-33). The results on the recommendation of the tool are similar in both groups.

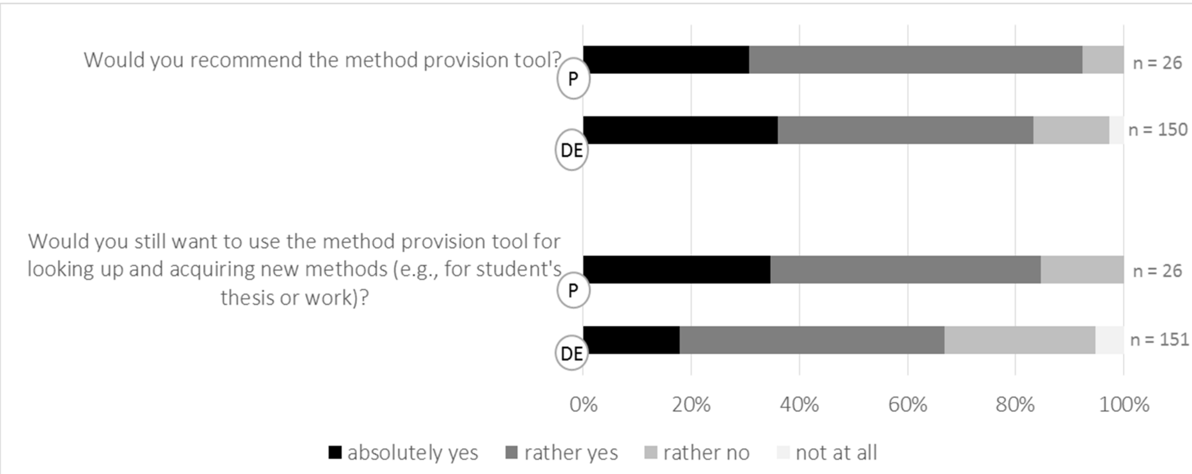


Figure 8-33 Comparison of the further usage and recommendation of the method provision tool in design education (DE) and practice (P)

8.5 Discussion of the results

As a conclusion for the method training in education and practice it is remarkable that the practitioners are less motivated to work on their own during a workshop to acquire new method knowledge whereas the students seem to be more motivated by self-learning phases during the classes. Outside the classroom or workshop, the students become less motivated to further work with the method provision tool to acquire new methods, where in contrast the practitioners indicate to further use the tool. The practice training concepts already try to consider these aspects by providing preparation phases with a core team for method selection and further agreements.

Regarding the method provision tool by means of the software demonstrator METHODOS the evaluations were quite positive. The acceptance of the tool and the knowledge about it is widely spread in design education due to the integration into most courses. The attributes chosen for the method description seem to be adequate in general. The same can be stated for the method access, whilst the comprehensibility of the access filter can be optimised in some aspects (e.g. *method classification*, *required materials* or *complexity of the upcoming task*).

The sample size and duration of 1.5 years of the evaluation study in design education give this study much more weight than the study in practice. The last-mentioned study is very small with only two investigated companies and few participants due to the training concept of small workshops. It has also to be mentioned that the usability of the method provision tool was only investigated in training situations meaning workshop environments and not in daily work situations within the companies. The practitioners of the core team (local workshop) used the method provision tool for preparation purpose during the series of workshops but the further usage, after the training was finished, was not evaluated. So, the conclusions made from the evaluation results are based on hypothetical questions on how the participants assume to further work with the tool. However, it can be assumed that a high acceptance and usage of a method provision tool in education lead to an enhanced application and usage of such a tool and also methods in practice in the long-term.

To avoid mixing of different effects within the evaluations, the competencies within the method provision tool were not evaluated as part of the software demonstrator. The impact model revealed the important aspects of method user characteristics regarding method application by expert ratings. Furthermore, some tests based on the concepts and scenarios presented in chapter 6 were successfully realised with an industry partner within a student's thesis (Hoyer, 2016). The team members chosen due to competencies matched the tasks very well and were also chosen by the team leader from their experience.

The results of the method provision tool and the selected team-oriented attributes were promising. Additionally, the sample from practice showed interest in further method user characteristics. Finally, the preparatory work needed is done to implement the competencies assessment and matching in the software demonstrator to do an overall testing of the team-oriented method provision tool.

9 CONCLUSION AND OUTLOOK

"You can never really judge your work
because once it's done, it's done."
Charlotte Rampling, British actress

This chapter will conclude the underlying research work by summing up and reflecting on the results. To do so, the first part of this chapter will summarise the work by highlighting the main results. The subsequent section is used to reflect on these results critically and to point out limitations to finally propose future steps of research within the last section of this thesis.

9.1 Summary of research results

The first chapter of this thesis was used to reference the problems resulting from more and more heterogeneous engineering design teams working at different places together. The main underlying assumption of this work is that engineering design methods can support these heterogeneous teams but the methods have to fit the method user characteristics. Thus, the development of a team-oriented method provision and training approach was stated as the main goal of this research. Therefore, the research methodology was explained and main assumptions and research questions were established and linked to the thesis' structure.

The subsequent state of the art presented basics for design methodology like assignment of the work to engineering design processes and basics on methods and their provision. Among the design organisation, teams and their characteristics were described, focussing also on the changing team constellations with increasingly more virtual teams and their particularities compared to traditional teams. As the final basis, knowledge transfer in general and specific challenges of method knowledge transfer in education and in practice were considered. Therefore, success factors and barriers for method knowledge transfer as found in literature were mentioned as well.

Summarizing the main findings of the state of the art, chapter 3 focuses on the identified research gap to further clarify the underlying problem of this thesis. The aim is to address the identified gap by three intended results: (1) a concept for a method provision tool for teams,

(2) an impact model for method user characteristics regarding methods, and (3) method training concepts for design education and practice were conceived.

To achieve the intended results, two analyses and two syntheses were necessary: The first was an analysis of existing method collections and method models regarding attributes for description and access. The analysis results were used to deduce requirements on method provision consisting of method description and method access in general. The requirements were broadened by results from a survey in practice. These requirements were the basis for the first synthesis aiming at the development of an impact model of method user characteristics on method application (intended result 2) and at the development of a concept for a team-oriented method provision tool (intended result 1). The impact model was obtained via a sensitivity analysis rated in cooperation of engineering designers and psychologists. Main findings of the impact model are that the most relevant method user characteristics are the four competence facets (*professional*, *social*, *methodological* and *self-competence*), *team size*, *multidisciplinarity*, *hierarchical* and *cultural differences*, *motivation*, as well as collaboration characteristics like *location*, *time* and *language*. These insights were subsequently used for the conception of the team-oriented method provision tool. This concept is based on the Process-oriented Method Model of Birkhofer, Kloberdanz, Berger et al. (2002) and consists of method specific, task / situation specific and team / user specific attributes, which were deduced in the impact model. An access algorithm considering team aspects was added to the concept. The application of the concept for the team-oriented method provision tool was demonstrated with the aid of exemplary scenarios. Additionally, a software demonstrator was presented, which was later used to realise the evaluation studies.

The second analysis aimed at the identification of requirements on method training and transfer. To do so, success factors and barriers for method transfer named in literature were analysed and finally requirements on successful training and transfer deduced. Thereby, a differentiation between requirements for students in design education and for practitioners in industry was made. The second synthesis builds on the deduced requirements from the prior analysis in chapter 5: first, general didactic media and other material for method knowledge transfer and training were conceived and implemented. Second, training concepts (intended result 3) for design education in an in-class course and an online course were developed. Similar concepts were designed for practice as a workshop-based training concept and a virtual training concept using online workshops.

To test the team-oriented method provision tool and the training concepts, evaluation studies were conducted on the usability of the tool in the form of the software demonstrator and in the different training set-ups in design education and practice. The results and a comparison of these in design education and in practice were presented in chapter 8. The evaluation results reveal similar ratings in both target groups on the software demonstrator of the method provision tool and some differences in the training concepts. In general, the concept of the method provision tool was awarded with good ratings on the method description and mainly good results on the method access. Some improvements on the access comprehensibility were highlighted. The integration of the method provision tool in training concepts was less appreciated in practice than it was in education but it still was positively rated in both target groups. Though, the practitioners would like to use the tool for their individual work or for preparation purpose, whereas the students prefer the usage of the tool within the course instead of on their own for project work or student's thesis.

9.2 Reflection of research results

Coming back to the underlying research methodology with the main assumptions and research questions of this thesis, each question shall be reflected on regarding the achieved results. The first assumption A1: *"The acceptance of applying engineering design methods is supported by a suitable method provision."* could already be based on the findings in literature, e.g. from Araujo, JR (2001) who dealt in detail with this topic and cited Hubka in this context "for a tool to become a successful instrument, its mode of operation must be sufficiently clearly and completely described." (Hubka, 1983) "Tool" means in the words of this thesis a "method". Hubka's solution of a catalogue aims primarily at the adequate "tool selection", which corresponds to the method access in this work.

The second part of the method provision, the method description, is highlighted, for instance, by Birkhofer, Kloberdanz, Berger et al. (2002) as the key aspect to successful method provision. To answer Q1: *"How are engineering design methods provided in existing method descriptions and collections?"*, an excessive analysis of existing, structured method collections and models was realised and presented in chapter 4. Therefore, 25 method collections and models were considered. The included attributes for description and access to those collections and models were analysed to derive requirements on a successful method provision and to answer research question Q2: *"What are requirements on a suitable method provision in engineering design?"* It could be identified that there is a discrepance between the attributes considered relevant in literature as mentioned in the state of the art and the results of the analysis of existing method collections and models.

To complete the findings with insights from practice, survey results from the MuPro-KMU study (Vietor, 2015) were compared and added. The analysis of the method collections and models revealed 42 different describing attributes for methods and some good examples of method provision with much information contained. Remarkable was that there was a low consideration of team-oriented attributes, only mentioning *method experience*, *team size*, *roles of the team*, *qualification of the team*. Hereby, the *roles of the team* and the *qualification* were quite similar meaning moderators or other specific abilities and skills required. However, many authors mention team or user (as the designer) aspects as relevant when deciding on a method, e.g. from Munich Braun (2005), Dylla (1991), Helbig (1994), Ponn (2007) or Wach (1994) or from Darmstadt Frankenberger (1997) and Grösser (1992), but in corresponding method provision approaches only these few attributes were realised.

Thus, a gap in the method provision could be identified being the consideration of the team or user of the method to be applied within the method provision. The relevance of this consideration could be confirmed by the impact model established in chapter 6, showing the influence of single method user characteristics on the method application. This model as a result of a collaboration between psychologists and engineering designers gives an answer to research question Q3: *"How do method user characteristics influence the methods' application in engineering design?"* The impact model additionally confirms the main assumption A2 for this work: *"Method user characteristics influence the selection of a suitable method in engineering design."* Based on these results combined with the requirements earlier set up, the research question Q4: *"How can method user characteristics be identified and considered in method provision and application?"* could be answered in means of a concept for an assessment tool for method user characteristics, a team-oriented method description model also providing a method access algorithm and a software demonstrator called METHODOS. The software demonstrator contains most of the proposed attributes of the method model and corresponding access possibilities as conceived. Additionally to the team-oriented attributes, some aspects mentioned in earlier research work to be worth working on (Ponn, 2007) like the provision of *practical examples*, a good usability (confirmed in the evaluation studies) and *commentary functions* for feedback were realised. Though, the software demonstartor was not intended to be a complete method provision tool with all features implemented. Thus, Q4 as one of the main research questions could be dealt with comprehensively. Exemplary scenarios helped to demonstrate the applicability of the proposed concept for a team-oriented method provision tool.

The final main assumption A3: *"To achieve a successful method knowledge transfer the target group has to be considered."* could be further confirmed by analysing existing literature on method transfer and training. Generally, a differentiation of transfer to practice and training in education is made. Only a few authors try to provide or consider training and transfer concepts for both, education and practice, e.g. Lenhart and Birkhofer (2006) with their user classification approach. The responses to the research questions Q5: *"What are success factors and barriers for method knowledge transfer in design education and practice?"* and Q6: *"What are successful means for method knowledge transfer considering the target group?"* were used to confirm the assumption A3. Q5 was answered by an analysis of existing work on success factors, barriers and requirements on method knowledge transfer and training. The analysis showed that most authors came up with the related success factors, barriers and resulting requirements. These requirements built the basis for the answer to Q6. To do so, the team-oriented method provision tool was integrated into training concepts for design education (in-class and online courses) and practice (in-class and online workshop). The evaluations of the software demonstrator of the method provision tool as well as of the training concepts realised in different set-ups, revealed good results meaning that the research questions could be answered satisfyingly.

Summing up, the method and the method provision were considered as a product and the engineering designer who applies the method as the product user in this thesis. Thus, the main contribution of this research work is the consideration of the design team as a product user in method provision. Additionally, training concepts integrating a team-oriented method provision were proposed for an overall successful team-oriented method training and transfer in both target groups, design education and practice.

9.3 Outlook and future work

As the approach to connect method user characteristics to information on methods in a team-oriented method provision, future steps have to be taken to implement the complete set of method user characteristics that have been identified as relevant in the impact model. Therefore, the software demonstrator METHODOS could serve as a basis for the integration of the complete assessment tool. The proposed mappings of method user characteristics to methods (see Appendix C4) have to be added to the method database, which is realisable with moderate effort due to the modular structure of the database. Having implemented the complete team-oriented method provision tool as conceived in this thesis, further testing in education and practice using the proposed training concepts could be conducted. As the sample size in practice was restricted to two companies, the realisation of further training could reveal additional and more profound insights on the demands of practice on team-oriented method provision and training. An important issue, being excluded in this thesis, is privacy protection. For further testing with the complete assessment tool, measures assuring the protection of sensitive personal data like competencies, have to be taken. This includes also a strategy who may decide on the team composition corresponding to the required method user characteristics.

As no differentiation between SME and OEM was made in this thesis, another interesting aspect would be the different demands on team-oriented method provision and also on method training depending on the size of the enterprise. The most relevant aspect in this context seems the availability of personnel. The composition of a team according to required characteristics is hindered by a limited access to resources in small- and medium-sized enterprises whereas OEMs normally are more flexible, for instance, for inviting persons to training.

Concerning the content of the method provision tool, the number of methods as well as the single elements for method training like method videos, templates and instructions could be extended. The methods selected are limited to those mainly taught within the design education at TU Braunschweig. Especially for practice, an extension would be necessary and fruitful, e.g. methods from other disciplines. Further methods can be explained by videos. Additionally provided templates could be elaborated and tested in education and practice. Especially in practice, the demand for templates was high to enable a quick application of methods without high preparatory effort for templates. Due to the increasing digitalisation of the daily life, the conception of further modern and interactive training media and formats is a potential and promising aspect of future research in design education in particular. A first step in this direction was the development of a blended online course, which contained amongst other online and digital material the software demonstrator of the method provision tool. Due to the potentially wide reach of such an online course, it is an adequate platform to conduct further evaluations of newly developed training material.

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Glossary

attribute
An attribute is a single element to describe a certain characteristic or characteristics of a method. Examples are the *method description* or the *team size* best fitting to apply a method.

cluster
In a cluster, there are merged multiple attributes that belong to a similar group. In this thesis four clusters are differentiated: *method specific*, *task / situation specific*, *team / user specific* attributes, and *additional content and tools.*

format
Format is defined as the way in which something is arranged or set out. (Oxford Dictionaries, 2017a)

media
Media is generally defined as a means by which something is communicated or expressed. (Oxford Dictionaries, 2017b)

method
A method provides an operatively applicable thinking and behaviour pattern to achieve a goal. (Vietor & Lachmayer, 2016)

method access
The method access determines the way to search, select or access methods. There are different possibilities like ma-trices of criteria or filter options.

method collection
A method collection consists at least of more than one method description. It serves the purpose to provide method knowledge to the user of the collection. It can be paper- or web-based.

method description
A method description contains infor-mation about a (design) method. In this thesis, only structured and uniform de-scriptions that describe each method with the same attributes are considered as method descriptions.

method description model
Method description models define in an abstract way how to describe a method in a structured manner by uniform attributes.

method knowledge
Method knowledge comprises all information and skills acquired to apply a method.

method knowledge transfer
= method training

method provision
Combining method descriptions with an access to the content is the provision of methods.

method training
Training is generally defined as the action of teaching a person or animal a particular

skill or type of behaviour. (Oxford Dictionaries, 2018b) In the context of method training, the knowledge to train is method knowledge.

method transfer

The transfer of deign methods from research to practice is mainly called method transfer.

team

A team is a social system consisting of three or more members, whose members perceive themselves as a team and are perceived as a team by others as well, and who collaborate to achieve a common goal. (Hoegl et al., 2001)

tool

A tool supports a method application by its inherent logic. (Vietor & Lachmayer, 2016)

value

Regarding method attributes with predetermined characteristics like the *team size* (1, 2-3, 4-6, 7 and more team members), values are the possible characteristics of the attribute. Some attributes like the *method description* do not provide values.

virtual team

A virtual team consists of individuals who are temporally, geographically, organisationally and/ or culturally dispersed and act interdependently through technology to achieve a common goal. A virtual team is embedded in an organisational setting. (Schumacher, 2011)

APPENDICES

A1 – List of method attributes, their description and origin separated by cluster

() in the last column indicate an indirect inclusion of the attribute in the collection

cluster	attribute	description	element of following collections and models
method specific	method name	Name of the method usually found in literature.	all collections and models
	synonym	Further method names found in literature which can be used synonymously.	DOBBERKAU, MAP-TOOL, MEPORT, PM, WIPRO
	description / portrait of me	Short general description of the method containing aims, the rough procedure and the results of the method usage.	BIRKHOFER, CIRCULAR, DESIGN COUNCIL, DESIGNKIT, (DMF), DOBBERKAU, (EVERSHEIM), GINA, INNOFOX, KUM, MAP-TOOL, (MARTIN), MEPORT, PONN, (SPP), (STRASSER), WIPRO
	short description	Very short description of the method in one to two sentences, mainly used for the first impression in an overview / index.	18F, 27C&I, CIRCULAR, DESIGNKIT, DMF, DMS, INNOFOX, INNOWISSEN, (IPH), MARTIN, MEDIALAB, PM, STRASSER
	illustration / picture	An illustration, picture or pictogram showing the method in general, main ideas or a result.	27C&I, CIRCULAR, DESIGN COUNCIL, DESIGNKIT, DMF, DOBBERKAU, (INNOFOX), (INNOWISSEN), IPH, (MAP-TOOL), MARTIN, MEDIALAB, PM, PONN, SPP
	procedure	A step-by-step procedure description enabling the method user to apply the method by the aid of the procedure description. In the best case, the steps are numbered.	18F, 27C&I, BIRKHOFER, CIDAD, CIRCULAR, (DESIGN COUNCIL), DESIGNKIT, (DMF), DOBBERKAU, (EVERSHEIM), GINA, INNOFOX, INNOWISSEN, IPH, KUM, MAP-TOOL, (MARTIN), MEDIALAB, MEPORT, PM, (PONN), SPP, (STRASSER), (WIPRO)
	notes (regarding procedure	The notes contain tips, hints and rules for the behaviour during the method application or suggest optional steps and further information regarding the method application.	BIRKHOFER, CIDAD, DOBBERKAU, (INNOFOX), INNOWISSEN, MEDIALAB, PM, STRASSER
	picture of procedure / flowchart	A flowchart or a picture of the procedure illustrates the steps to be applied to fulfil the method.	BIRKHOFER, DMF, (INNOFOX), (INNOWISSEN), MEPORT
	strength / advantages	Strength as well as advantages show positive aspects of the method, mainly compared to other methods or compared to fulfilling the task without a method.	DMF, EVERSHEIM, GINA, INNOFOX, INNOWISSEN, IPH, KUM, MAP-TOOL, MEPORT, PM, WIPRO
	weaknesses / disadvantages	Weaknesses as well as disadvantages show negative aspects of the method, mainly compared to other methods or compared to fulfilling the task without a method.	DMF, EVERSHEIM, GINA, INNOFOX, INNOWISSEN, IPH, KUM, MAP-TOOL, MEPORT, PM, WIPRO
	materials required	Materials that are required or maybe optional to apply the method in a correct manner.	BIRKHOFER, DESIGNKIT, DOBBERKAU, INNOFOX, MAP-TOOL, MEPORT, PM, STRASSER
	models obtained	The results of most method applications are models within the design process like sketches or lists.	KUM
	effort of materials	The effort of materials indicates the amount of materials in general to provide for the method application.	STRASSER
	related methods	Related methods are similar methods that can mainly be applied instead of the method in question.	BIRKHOFER, CIRCULAR, DESIGNKIT, DMF, GINA, INNOFOX, MARTIN, PM, STRASSER, WIPRO

cluster	attribute	description	element of following collections and models
method specific	synergies with other methods	Synergies can be formed with other methods, if the results of one method are the input for another method. Applying both methods can allow advantages.	BIRKHOFER, DMF, STRASSER
	variants or adaptions of method	If the circumstances do not allow the method use as proposed, variants or adaptions offer further possibilities to apply the method without changing the idea of the method.	DOBBERKAU, KUM, (MAP-TOOL), PM, (STRASSER)
	adaptability of method	The adaptability indicates the degree of flexibility regarding adaptions of a method. A high adaptability allows adaptions to various situations and circumstances.	KUM
	author of the method	The author of the method itself can reveal the way to original literature on a method.	EVERSHEIM, (MARTIN)
	background information	Background information on a method can be the history of the method, further interesting facts or other information not matching the other attributes.	BIRKHOFER, (MARTIN), PM
	literature on method	Possible literature that provides further insights into the method and its application.	18F, 27C&I, BIRKHOFER, CIDAD, DMF, EVERSHEIM, GINA, INNOFOX, INNOWISSEN, IPH, KUM, MAP-TOOL, MARTIN, MEPORT, PM, SPP, STRASSER, WIPRO
	preparatory steps	Steps to be done before starting the method itself. Mostly, these steps are included in the procedure or obvious like finding a room for a meeting with more than two persons.	DMF, KUM, (MAP-TOOL), MEPORT
	preparatory effort	The effort for preparation indicates how much time has to be spent before the method application can start.	INNOFOX, (STRASSER)
	training effort	The effort for training indicates how much time has to be spent to train the user or the team involved in the method application before they can use the method.	KUM, STRASSER
	time requirements / effort	The average time required to apply the method. This depends also on the task to deal with.	18F, DESIGNKIT, INNOFOX, KUM, MEDIALAB, PM, STRASSER, WIPRO
	continuous time requirements	The continuous time requirements indicate whether a method is used once or during the complete design process repeating.	WIPRO
	ratio: benefit/effort	The ratio of benefit and effort indicates the performance of a method. This ratio is vague due to interdependencies to various factors like the circumstances of the method usage.	KUM
	relevance of method	The relevance of the method depends on the reference of relevance. It can be the relevance, e.g. for small and medium sized enterprises.	KUM

cluster	attribute	description	element of following collections and models
task / situation specific	method classification	The classification of methods can be done in different ways. This attribute only indicates whether a classification was conducted. It suggests no predefined classification. Typical classifications are according to the method aim like evaluation methods, ideation methods, etc.	(BIRKHOFER), DESIGNKIT, DMF, EVERSHEIM, GINA, (MAP-TOOL), (MARTIN), MEDIALAB, MEPORT, (PM), (PONN), STRASSER, WIPRO
	process phase	Process phases can be defined according to various process models, thus, there are no predefined values for this attribute. A possible process is the design process by Pahl and Beitz.	18F, (BIRKHOFER), CIRCULAR, DESIGN COUNCIL, DESIGNKIT, DMF, EVERSHEIM, (INNOFOX), (MAP-TOOL), MARTIN, (MEDIALAB), MEPORT, (PONN)
	general design activities	These general design activities indicate mainly the aim of a method application using basic design activities like generating ideas.	BIRKHOFER, (CIDAD), (CIRCULAR), DMF, DOBBERKAU, (INNOFOX), KUM, (MARTIN), (MEDIALAB), MEPORT, PM, (PONN), WIPRO
	aim of method usage	The aim of a method usage is similar to the focus of general design activities but instead of these activities, textual descriptions are used.	(18F), BIRKHOFER, (CIDAD), DESIGN COUNCIL, (DMF), DMS, DOBBERKAU, (EVERSHEIM), (GINA), INNOWISSEN, IPH, (MEDIALAB), (PONN), (SPP), STRASSER, WIPRO
	complexity of upcoming task	The complexity of the upcoming task indicates the degree of difficulty of the upcoming task that can be dealt with while using the method in question.	STRASSER
	input / problem	The input can be also problems that are the starting point of the method application.	BIRKHOFER, (27C&I), (CIDAD), DOBERKAU, EVERSHEIM, INNOFOX, INNOWISSEN, (MAP-TOOL), (MEDIALAB), MEPORT, PM, (PONN), SPP, WIPRO
	output / results	The output of a method equals the results of the method application.	BIRKHOFER, (CIDAD), DESIGN COUNCIL, DOBERKAU, EVERSHEIM, (GINA), INNOFOX, INNOWISSEN, MEDIALAB, MEPORT, PM, (PONN), SPP, WIPRO
	orientation of results	The orientation of results indicates the procedure and kind of results achievable with the method. Mainly there are divergent, increasing the solution space and quantitative methods and convergent, narrowing down the solution space, qualitative methods.	MARTIN, MEDIALAB, STRASSER
	product type or domain of application	The domain of application names typical domains where the method is applied. Furthermore, the attribute gives insight of the appropriate product type, like a physical product or a service.	18F, 27C&I, (BIRKHOFER), DMS, (DOBBERKAU), (INNOFOX), (MAP-TOOL), MEPORT, (PM), (STRASSER)
	size of company	Due to personal and material restrictions not any method can be applied in every company. Thus, this attributes indicates the suitability of the method regarding the size of a company.	(BIRKHOFER), WIPRO
	suitability for open innovation	The suitability for open innovations describes the possibility to apply the method in an open innovation context in which other external stakeholders are involved in the method application.	WIPRO

cluster	attribute	description	element of following collections and models
team / user specific	team size (group <-> individual)	The team size indicates the appropriate number of team members to apply the method. Sometimes, only the information whether the method suits for individuals or for groups is given.	27C&I, (DESIGN COUNCIL), DOBBERKAU, (GINA), INNOFOX, (IPH), (MEPORT), PM, STRASSER, (WIPRO)
	roles within team (e.g. moderator)	Beside normal participants, some methods require certain roles, like moderators. This attribute indicates roles needed except for normal users.	(CIDAD), DOBBERKAU, (GINA), INNOFOX, (IPH), (KUM), (MAP-TOOL), (MARTIN), (MEDIALAB), (MEPORT), PM, (PONN), STRASSER, (WIPRO)
	qualification of team	The qualification of the team indicates whether special knowledge, competencies or experts are needed to apply the method.	BIRKHOFER, (CIDAD), DESIGNKIT, (EVERSHEIM), (GINA), (IPH), (KUM), (MARTIN), (MEPORT), PM, (PONN), (STRASSER)
	experience with method usage	The experience with method usage describes the degree of difficulty of a method from a methodical point of view. The more experience is needed, the more difficult is a method.	BIRKHOFER, DESIGNKIT, INNOFOX, KUM, PM

cluster	attribute	description	element of following collections and models
additional content and tools	multilingualism	The multilingualism describes the possibility to use the collection or the model in different languages.	(PM)
	help function and support	Help function and support assist the user of the method collection or model to understand how to deal with it. This can be manuals, support videos or help hotlines.	CIDAD, DESIGN COUNCIL, (DMF), INNOFOX, (IPH), (KUM), MAP-TOOL, (MARTIN), MEPORT, (PM), (STRASSER)
	accessing possibilities (filter, selection criteria)	This attribute indicates the existence of filter and selection options to easier find relevant methods.	all collections and models except for DMS; different access possibilities
	provision or links to tools and templates	The provision of tools and templates or the links towards them simplify the method application as tools and templates do not have to be elaborated before starting the method. Templates and tools can be exemplary little programs or predefined sheets.	BIRKHOFER, CIDAD, CIRCULAR, GINA, (INNOFOX), INNOWISSEN, (MAP-TOOL), MEPORT, PM, SPP, (STRASSER)
	practical examples (own upload)	Practical examples demonstrate the application of a method using a real example from practice. Own upload means that the user can upload his or her examples to share it with others.	27C&I, BIRKHOFER, CIDAD, (DESIGN COUNCIL), (DMF), (INNOFOX), (INNOWISSEN), (IPH), (MAP-TOOL), MARTIN, (MEPORT), PM, SPP
	video tutorials / method videos	Videos can be another format to describe methods. Mostly, they are used in addition to textual descriptions. Videos explaining methods are called in the following method videos.	BIRKHOFER, (CIRCULAR), DMS
	commentary function	Commentary functions enable the user of a method to comment on the method and to share his or her experiences.	EVERSHEIM, PM, WIPRO
	evaluation function	Evaluation functions enable the user of a method to evaluate his or her experiences with a method application.	EVERSHEIM, DMF, (INNOFOX), PM
	links to consultants or support	Especially for more difficult methods the guidance of an method expert or consultant is reasonable. Links can help to find suitable experts.	CIRCULAR, GINA, INNOFOX, (INNOWISSEN), MEPORT, PM, SPP, WIPRO
	presentation / download for training purpose	In case that not all team members are familiar with the method to be applied, the provision of training material like a presentation demonstrating a method description is helpful. This attributes indicates if such presentations or material are available.	(CIDAD), (GINA), (MAP-TOOL), MEPORT, PM, SPP
	content overview	Mainly for detailed method descriptions, an overview over all describing attributes is helpful. Possible formats are , e.g. dropdowns or a separated content overview.	GINA, INNOFOX, MAP-TOOL, (MEPORT), PM, SPP
	keywords	The provision of keywords for each method provides another dimension for describing a method. The keywords can be derived from various fields.	BIRKHOFER, (CIDAD), DMF, (GINA), (INNOWISSEN), PM

A2 – Complete evaluation tables of method description analysis separated by cluster

method description models, method collections	formalities: number of methods described	general quality of method descriptions	clear layout and arrangement	intuitiveness and comprehensibility	general quality and simplicity of applicability	hints and remarks
paper-based method description models / method collections						
BIRKHOFER, 2002	○	–	–	–	–	not evaluated as no concrete description is available
DESIGN COUNCIL	◔	◑	◕	◑	◑	
DOBBERKAU, 2002	◑	◕	●	●	◑	
EVERSHEIM, 2003	◕	◕	●	●	◑	
IPH, 2009	◕	◕	●	●	◑	
KUM, 2015	◑	●	●	◕	◑	
MARTIN, 2013	●	◑	◑	◑	◑	
PONN, 2007	◕	◕	●	●	◑	
SPP, 2004	◔	◑	◕	◑	–	application not in evidence with one description
STRASSER, 2004	◕	●	●	◕	◑	
web-based method description models / method collections and mobile applications						
18F	◕	◑	◕	◕	◕	
27C&I, 2013	◑	◑	◑	◑	◔	presented as a slide show
CIDAD, 2008	◕	◑	◕	●	◔	many other functionalities and information hinder an easy usage of the portal
CIRCULAR, 2016	◑	◑	◕	◕	◕	focus an method variants for circular design
DESIGNKIT	◑	◕	●	●	●	
DMF, 2010	◕	◑	●	●	◕	
DMS, 2012/13	◔	◔	◕	◕	●	
GINA, 2004	◕	◕	◕	◕	◕	
INNOFOX, 2014	◕	◑	●	●	◕	the quality of method descriptions varies strongly
INNOWISSEN, 2004	◕	◑	●	●	●	
MAP-TOOL, 2000	●	◑	◑	◑	◑	the quality of method descriptions varies strongly
MEDIALAB	◕	◕	●	●	●	
MEPORT, 2009	◕	●	◕	◕	◕	
PM, 2015	◕	●	●	●	●	
WIPRO, 2013	●	●	●	●	●	

(row label column: author or name of method description model / collection)

method description models, method collections — author or name of method description model / collection	method name	synonym	description / portrait of method	short description	illustration / picture	procedure	notes (regarding procedure)	picture of procedure / flowchart	strength / advantages	weaknesses / disadvantages	materials required	models obtained	effort of materials	related methods
paper-based method description models / method collections														
BIRKHOFER, 2002*	●	○	●	○	○	●	●	●	○	○	●	○	○	●
DESIGN COUNCIL	●	○	●	○	●	◐	○	○	○	○	○	○	○	○
DOBBERKAU, 2002	●	●	●	○	●	●	●	○	○	○	●	●	○	○
EVERSHEIM, 2003	●	○	◐	○	○	◐	○	○	●	●	○	○	○	○
IPH, 2009	●	○	○	◐	●	●	○	○	●	●	○	○	○	○
KUM, 2015	●	○	●	○	○	●	○	○	●	●	○	○	○	○
MARTIN, 2013	●	○	◕	●	●	◔	○	○	○	○	○	○	○	●
PONN, 2007	●	○	●	○	●	◔	○	○	○	○	○	○	○	○
SPP, 2004	●	○	◐	○	●	●	○	○	○	○	○	○	○	○
STRASSER, 2004	●	○	◐	●	○	◐	●	○	○	○	●	○	●	●
web-based method description models / method collections and mobile applications														
18F	●	○	○	●	○	●	○	○	○	○	○	○	○	○
27C&I, 2013	●	○	○	●	●	●	○	○	○	○	○	○	○	○
CIDAD, 2008	●	○	○	○	○	●	●	○	○	○	○	○	○	○
CIRCULAR, 2016	●	○	●	●	●	●	○	○	○	○	○	○	○	●
DESIGNKIT	●	○	●	●	●	●	○	○	○	○	●	○	○	●
DMF, 2010	●	○	◐	●	●	◐	○	●	●	●	○	○	○	●
DMS, 2012/13	●	○	○	●	○	○	○	○	○	○	○	○	○	○
GINA, 2004	●	○	●	○	○	●	○	○	●	●	○	○	○	●
INNOFOX, 2014	●	○	●	●	◔	●	◔	◔	●	●	●	○	○	●
INNOWISSEN, 2004	●	○	○	●	◔	●	●	◔	●	●	○	○	○	○
MAP-TOOL, 2000	●	●	●	○	◔	●	○	○	●	●	●	○	○	○
MEDIALAB	●	○	○	●	●	●	●	○	○	○	○	○	○	○
MEPORT, 2009	●	●	●	○	○	●	○	●	●	●	●	○	○	○
PM, 2015	●	●	○	●	●	●	●	○	●	●	●	○	○	●
WIPRO, 2013	●	●	●	○	○	◐	○	○	●	●	○	○	○	●

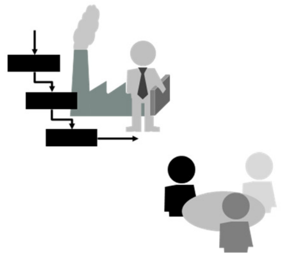
(Column group heading: **method specific I**)

* only assumed from model, as no concrete description is available

method description models, method collections	author or name of method description model / collection	synergies with other methods	variants or adaptions of method	adaptability of method	author of the method	background information	literature on method	preparatory steps	preparatory effort	training effort	time requirements / effort	continuous time requirements	ratio: benefit/effort	relevance of method
paper-based method description models / method collections														
	BIRKHOFER, 2002*	●	○	○	○	●	●	○	○	○	○	○	○	○
	DESIGN COUNCIL	○	○	○	○	○	○	○	○	○	○	○	○	○
	DOBBERKAU, 2002	○	●	○	○	○	○	○	○	○	○	○	○	○
	EVERSHEIM, 2003	○	○	○	●	○	●	○	○	○	○	○	○	○
	IPH, 2009	○	○	○	○	○	●	○	○	○	○	○	○	○
	KUM, 2015	○	●	●	○	○	●	●	○	●	●	○	●	●
	MARTIN, 2013	○	○	○	◐	◐	●	○	○	○	○	○	○	○
	PONN, 2007	○	○	○	○	○	○	○	○	○	○	○	○	○
	SPP, 2004	○	○	○	○	○	●	○	○	○	○	○	○	○
	STRASSER, 2004	●	◔	○	○	○	●	○	◐	●	●	○	○	○
web-based method description models / method collections and mobile applications														
	18F	○	○	○	○	○	●	○	○	○	●	○	○	○
	27C&I, 2013	○	○	○	○	○	●	○	○	○	○	○	○	○
	CIDAD, 2008	○	○	○	○	○	●	○	○	○	○	○	○	○
	CIRCULAR, 2016	○	○	○	○	○	○	○	○	○	○	○	○	○
	DESIGNKIT	○	○	○	○	○	○	○	○	○	●	○	○	○
	DMF, 2010	●	○	○	○	○	●	●	○	○	○	○	○	○
	DMS, 2012/13	○	○	○	○	○	○	○	○	○	○	○	○	○
	GINA, 2004	○	○	○	○	○	●	○	○	○	○	○	○	○
	INNOFOX, 2014	○	○	○	○	○	●	○	●	○	●	○	○	○
	INNOWISSEN, 2004	○	○	○	○	○	●	○	○	○	○	○	○	○
	MAP-TOOL, 2000	○	◔	○	○	○	●	◔	○	○	○	○	○	○
	MEDIALAB	○	○	○	○	○	○	○	○	○	●	○	○	○
	MEPORT, 2009	○	○	○	○	○	●	●	○	○	○	○	○	○
	PM, 2015	○	●	○	○	●	●	○	○	○	●	○	○	○
	WIPRO, 2013	○	○	○	○	○	●	○	○	○	●	●	○	○

method specific II

* only assumed from model, as no concrete description is available



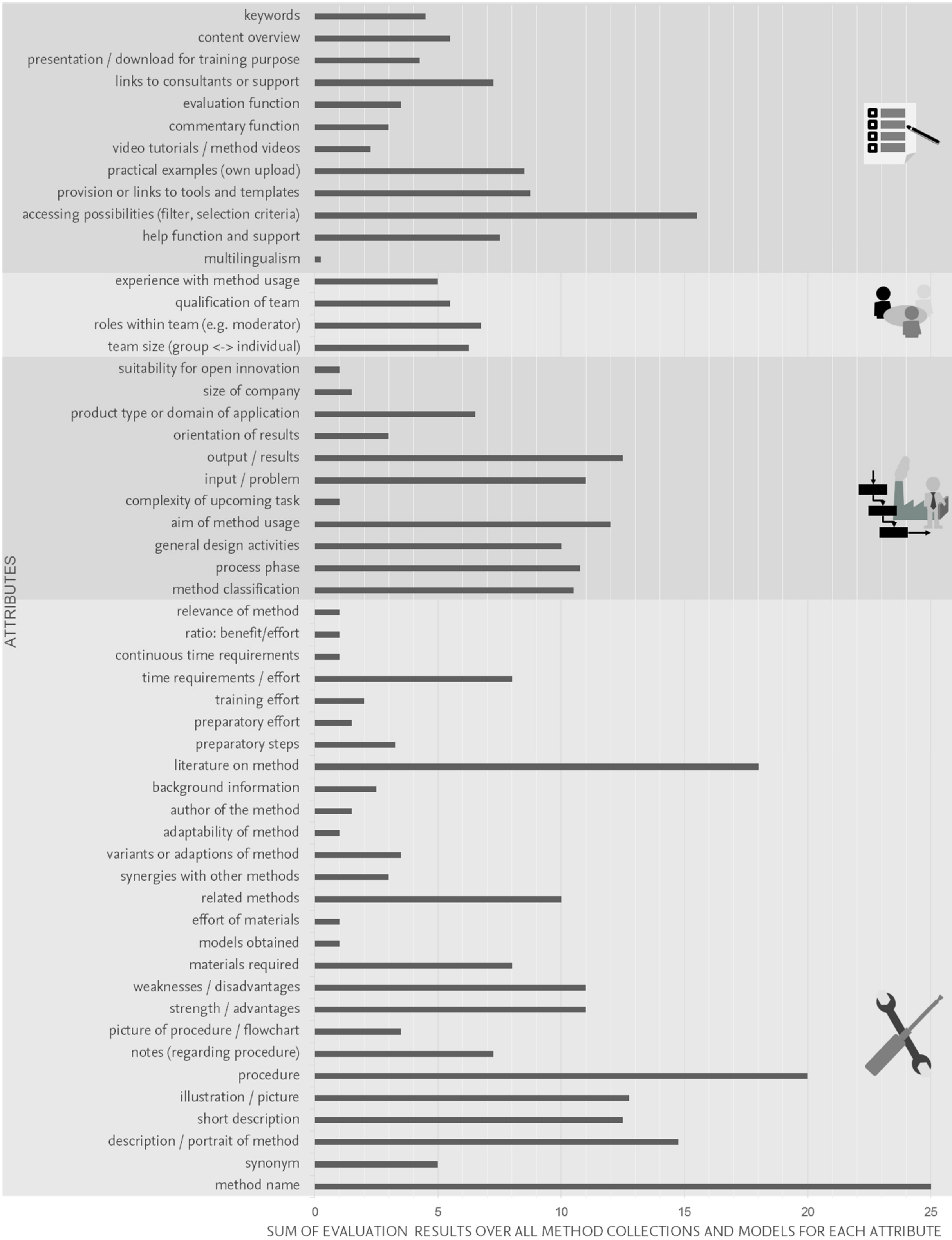
		task / situation specific											team/ user specific			
		method classification	process phase	general design activities	aim of method usage	complexity of upcoming task	input / problem	output / results	orientation of results	product type or domain of application	size of company	suitability for open innovation	team size (group <-> individual)	roles within team (e.g. moderator)	qualification of team	experience with method usage
method description models, method collections	paper-based method description models / method collections															
	author or name of method description model / collection															
	BIRKHOFER, 2002*	◑	◑	●	●	○	●	●	○	◑	◑	○	○	○	●	●
	DESIGN COUNCIL	○	●	○	●	○	○	●	○	○	○	○	◔	○	○	○
	DOBBERKAU, 2002	○	○	●	●	○	●	●	○	◑	○	○	●	●	○	○
	EVERSHEIM, 2003	●	●	○	◑	○	●	●	○	○	○	○	○	○	◔	○
	IPH, 2009	○	○	○	●	○	○	○	○	○	○	○	◔	◔	◔	○
	KUM, 2015	○	○	●	○	○	○	○	○	○	○	○	○	◔	◔	●
	MARTIN, 2013	◑	●	◑	○	○	○	○	●	○	○	○	○	◔	◔	○
	PONN, 2007	◑	◑	◑	◑	○	◑	◑	○	○	○	○	○	◔	◔	○
	SPP, 2004	○	○	○	◑	○	●	●	○	○	○	○	○	○	○	○
	STRASSER, 2004	●	○	○	●	●	○	○	●	◔	○	○	●	●	◔	○
	web-based method description models / method collections and mobile applications															
	author or name of method description model / collection															
	18F	○	●	○	◑	○	○	○	○	●	○	○	○	○	○	○
	27C&I, 2013	○	○	○	○	○	◔	○	○	●	○	○	●	○	○	○
	CIDAD, 2008	○	○	◑	◑	○	◑	◑	○	○	○	○	○	◔	◔	○
	CIRCULAR, 2016	○	●	◑	○	○	○	○	○	○	○	○	○	○	○	○
	DESIGNKIT	●	●	○	○	○	○	○	○	○	○	○	○	○	●	●
	DMF, 2010	●	●	●	◑	○	○	○	○	○	○	○	○	○	○	○
	DMS, 2012/13	○	○	○	●	○	○	○	○	●	○	○	○	○	○	○
	GINA, 2004	●	○	○	◑	○	○	◑	○	○	○	○	◔	◔	◔	○
	INNOFOX, 2014	○	◑	◑	○	○	●	●	○	◑	○	○	●	●	○	●
	INNOWISSEN, 2004	○	○	○	●	○	●	●	○	○	○	○	○	○	○	○
	MAP-TOOL, 2000	◑	◑	○	○	○	◔	○	○	◔	○	○	○	◑	○	○
	MEDIALAB	●	◕	◑	◑	○	◑	●	●	○	○	○	○	◔	○	○
	MEPORT, 2009	●	●	●	○	○	●	●	○	●	○	○	◔	◔	◑	○
	PM, 2015	◑	○	●	○	○	●	●	○	◑	○	○	●	●	●	●
	WIPRO, 2013	●	○	●	●	○	●	●	○	○	●	●	◔	◔	○	○

*** only assumed from model, as no concrete description is available**

method description models, method collections	additional content and tools: multilingualism	help function and support	accessing possibilities (filter, selection criteria)	provision or links to tools and templates	practical examples (own upload)	video tutorials / method videos	commentary function	evaluation function	links to consultants or support	presentation / download for training purpose	content overview	keywords
paper-based method description models / method collections (author or name of method description model / collection)												
BIRKHOFER, 2002*	○	○	◔	●	●	●	○	○	○	○	○	●
DESIGN COUNCIL	○	●	◑	○	◔	○	○	○	○	○	○	○
DOBBERKAU, 2002	○	○	◔	○	○	○	○	○	○	○	○	○
EVERSHEIM, 2003	○	○	◑	○	○	○	●	●	○	○	○	○
IPH, 2009	○	◔	◔	○	◑	○	○	○	○	○	○	○
KUM, 2015	○	◑	◑	○	○	○	○	○	○	○	○	○
MARTIN, 2013	○	◑	◑	○	●	○	○	○	○	○	○	○
PONN, 2007	○	○	◑	○	○	○	○	○	○	○	○	○
SPP, 2004	○	○	◔	●	●	○	○	○	●	●	●	○
STRASSER, 2004	○	◑	◑	◔	○	○	○	○	○	○	○	○
web-based method description models / method collections and mobile applications (author or name of method description model / collection)												
18F	○	○	◕	○	○	○	○	○	○	○	○	○
27C&I, 2013	○	○	◔	○	●	○	○	○	○	○	○	○
CIDAD, 2008	○	●	◑	●	●	○	○	○	○	◑	○	◑
CIRCULAR, 2016	○	○	●	●	○	◔	○	○	●	○	○	○
DESIGNKIT	○	○	●	○	○	○	○	○	○	○	○	○
DMF, 2010	○	◑	●	○	◑	○	○	●	○	○	○	●
DMS, 2012/13	○	○	○	○	○	●	○	○	○	○	○	○
GINA, 2004	○	○	●	●	○	○	○	○	●	◑	●	◑
INNOFOX, 2014	○	●	●	◔	◔	○	○	◑	●	○	●	○
INNOWISSEN, 2004	○	○	◔	●	◔	○	○	○	◔	○	○	◑
MAP-TOOL, 2000	○	●	◕	◔	◔	○	○	○	○	◔	●	○
MEDIALAB	○	○	●	○	○	○	○	○	○	○	○	○
MEPORT, 2009	○	●	●	●	◑	○	○	○	●	●	◑	○
PM, 2015	◔	◔	●	●	●	○	●	●	●	●	●	●
WIPRO, 2013	○	○	●	○	○	○	●	○	●	○	○	○

* only assumed from model, as no concrete description is available

A3 – Complete analysis result for method descriptions

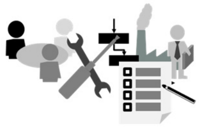


A4 – Complete evaluation table of method access analysis for access types and attributes

method description models, method collections	formalities				access types												
					paper-based				web-based								
author or name of method description model / collection	general quality of access logic / algorithm	clear layout and arrangement	intuitiveness and comprehensibility	general quality and simplicity of applicability	via matrices	via lists	via graphical mapping (like process)	via further mapping technique	via filter (filters list regarding applied filters)	via search options (selecting multiple options and getting results)	via user-defined text	via lists (e.g. as ABC list, as tiles arranged)	via matrices	via questions	via examples (suggested methods for an exemplary situation)	via graphical mapping	via (process) models
paper-based method description models / method collections																	
BIRKHOFER, 2002*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DESIGN COUNCIL	◕	●	●	◑	○	○	●	●	-	-	-	-	-	-	-	-	-
DOBBERKAU, 2002	◔	◔	◔	◔	○		○	○	-	-	-	-	-	-	-	-	-
EVERSHEIM, 2003	◕	●	●	◑	●	○	○	○	-	-	-	-	-	-	-	-	-
IPH, 2009	◔	●	●	◔	○	●	○	○	-	-	-	-	-	-	-	-	-
KUM, 2015	●	◕	◑	◑	●	●	○	○	-	-	-	-	-	-	-	-	-
MARTIN, 2013	◑	●	◕	◕	○	●	○	●	-	-	-	-	-	-	-	-	-
PONN, 2007	◕	◑	◕	◑	●	○	○	○	-	-	-	-	-	-	-	-	-
SPP, 2004*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
STRASSER, 2004	◕	◑	◕	◑	○	●	●	○	-	-	-	-	-	-	-	-	-
web-based method description models / method collections and mobile applications																	
18F	◕	◕	◕	◑	-	-	-	-	●	○	○	○	○	○	○	○	◑
27C&I, 2013	◑	◑	◕	◔	-	-	-	-	○	○	○	●	○	○	○	○	○
CIDAD, 2008	◑	◑	◔	◑	-	-	-	-	●	○		●	○	○	○	○	○
CIRCULAR, 2016	◕	●	◕	◕	-	-	-	-	●	○	●	●	○	○	●	○	◑
DESIGNKIT	◕	●	◕	◕	-	-	-	-	●	○	○	●	○	●	○	○	◑
DMF, 2010	●	●	◕	◕	-	-	-	-	●	●	●	●	○	○	○	●	◑
DMS, 2012/13	○	○	○	○	-	-	-	-	○	○	○	○	○	○	○	○	○
GINA, 2004	◑	◑	◕	◑	-	-	-	-	○	●	●	●	○	○	○	○	◑
INNOFOX, 2014	●	◕	◑	◑	-	-	-	-	●	●	○	●	●	●	○	○	●
INNOWISSEN, 2004	◔	●	●	◔	-	-	-	-	○	○	○	●	○	○	○	○	○
MAP-TOOL, 2000	◕	◔	◔	◑	-	-	-	-	●	○	○	●	●	○	○	○	◑
MEDIALAB	●	●	◕	◕	-	-	-	-	●	●	○	●	○	○	○	○	◑
MEPORT, 2009	◕	◕	◑	◑	-	-	-	-	●	●	●	●	○	○	○	○	◑
PM, 2015	◕	●	●	◕	-	-	-	-	●	○	●	●	○	○	○	○	○
WIPRO, 2013	●	●	●	●	-	-	-	-	●	●	●	●	○	○	○	○	○

*not available, as no concrete access example is available

Analysis of accessing attributes



method description models, method collections	method specific											task / situation specific							user specific			additional content
author or name of method description model / collection	method name	synonym	materials required	related methods	adaptability of method	preparatory effort	training effort	time requirements	continous time requirements	ratio: benefit/effort	relevance of method	method classification	process phase	general design activities	product type or domain of application	size of company	orientation of results	suitability for open innovation	team size (group <-> individual)	roles within team (e.g. moderator)	experience with method usage	keywords
paper-based method description models / method collections																						
BIRKHOFER, 2002*	●	○	○	●	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○
DESIGN COUNCIL	●	○	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○
DOBBERKAU, 2002	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
EVERSHEIM, 2003	●	○	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○
IPH, 2009	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
KUM, 2015	●	○	○	○	●	○	●	●	○	●	●	●	○	○	○	○	○	○	○	○	○	○
MARTIN, 2013	●	○	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○
PONN, 2007	●	○	○	○	○	○	○	○	○	○	○	●	●	●	○	○	○	○	○	○	○	○
SPP, 2004*	●	○	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○
STRASSER, 2004	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
web-based method description models / method collections and mobile applications																						
18F	●	○	○	○	○	○	○	○	○	○	○	○	●	●	○	○	○	○	○	○	○	○
27C&I, 2013	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
CIDAD, 2008	●		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
CIRCULAR, 2016	●	●	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○
DESIGNKIT	●	○	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	○	○
DMF, 2010	●	●	○	○	○	○	○	○	○	○	○	●	●	●	○	○	○	○	○	○	○	●
DMS, 2012/13	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
GINA, 2004	●	●	○	○	○	○	○	○	○	○	○	●	●	●	○	○	○	○	○	○	○	●
INNOFOX, 2014	●	○	●	○	○	●	○	●	○	○	○	●	●	●	○	○	○	○	●	●	●	○
INNOWISSEN, 2004	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
MAP-TOOL, 2000	●	○	○	○	○	○	○	○	○	○	○	○	●	●	○	○	○	○	○	○	○	○
MEDIALAB	●	○	○	○	○	○	○	●	○	○	○	○	●	●	○	○	●	○	○	○	○	○
MEPORT, 2009	●	●	○	○	○	○	○	○	○	○	○	○	●	●	●	○	○	○	○	○	○	○
PM, 2015	●	●	○	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○	●
WIPRO, 2013	●	●	○	○	○	○	○	●	●	○	○	○	●	○	○	●	○	●	●	○	○	●

* only assumed from model or description, as no concrete method description and access is available (Birkhofer: the attribute "restrictions" covers a wide field)

A5 – Final requirements list for a team-oriented method provision

organisation:		**product:** **method provision tool**		**date: 26/09/2017** **version no.: 01**	
INSTITUT FÜR KONSTRUKTIONSTECHNIK		**requirements list**		**editor: Bavendiek**	
structure	**no.**	**name**	**data, values**	**req. type**	**source, comment**
1.formalities	1.1	structured and uniform description	same attributes for each method	E	MuPro-KMU survey
	1.2	simple usage and application (of method provision tool)	simple	O	MuPro-KMU survey
	1.3	clear layout and arrangement	clear	E	Hubka (1983)
	1.4	good intuitivemeness and comprehensibility	good	O	
	1.5	number of methods included	from design education courses defined	M	IK
	1.6	focus on output	highlight results	E	MuPro-KMU survey
	1.7	high quality of method descriptions in all languages	application of method possible without further help, consistent quality for all languages	E	sensitivity analysis in chapter 6
	1.8	no costs for students	free access	E	IK
	1.9	optional costs for industrial practitioners	do be defined	O	MuPro-KMU survey
	1.10	provide multiple languages for globally distributed teams	German, English	E	sensitivity analysis in chapter 6
2. access to methods	2.1	web-based access	via a web portal/ digitally available	E	MuPro-KMU survey sensitivity analysis in chapter 6
	2.2	simltaneous access for multiple user	at same time	E	MuPro-KMU survey
	2.3	access via general design activities	using search options / reduction filter	E	MuPro-KMU survey
	2.4	access via boundary conditions	using search options / relevance filter	E	MuPro-KMU survey

	2.5	areas of boundary conditions	design task company user	E	MuPro-KMU survey
	2.6	overview of content in search results	using a short description (as attribute)	O	literature analysis
3. content of method descriptions	3.1	considering method specific attributes	method name synonym description illustration procedure further optional attributes	E	literature analysis
	3.2	considering task specific attributes	method classification process phase input output	E	literature analysis
	3.3	considering team / user specific attributes	team size team qualifications experience with method usage role within team	E	literature analysis
	3.4	considering practitioners demands	tips for application practical examples tutorials/videos	E	MuPro-KMU survey
	3.5	considering further team and method user characteristics	multi-disciplinarity hierarchical differences cultural differences professional competence social competence methodological competence self-competence location time language	E	sensitivity analysis in chapter 6 (without attributes from literature)
	3.6	including hints for virtual teams on how to adapt methods	suggestions for adaptions	E	sensitivity analysis in chapter 6

4. additional content for method provision tool	4.1	suggesting literature in general	not bound to single methods	O	MuPro-KMU survey and literature analysis
	4.2	explanation of important terms	glossary	E	MuPro-KMU survey
	4.3	help service and support	introduction video, FAQ	E	MuPro-KMU survey
	4.4	providing templates and links	templates for method application and downloads	E	MuPro-KMU survey
5. training and learning methods (in general)	5.1	low time effort for learning method	t ≲ 10 min	M	MuPro-KMU survey
	5.2	pilot projects or/and usage of real design tasks		O	literature review
	5.3	training and provision of support		E	literature review
	5.4	involvement of designers in method selection		E	literature review
	5.5	provision of reflection and experience exchange possibilities		E	literature review
	5.6	offer training/action possibilities		E	literature review
	5.7	fast transparent benefits		O	literature review
	5.8	quick results and time saving through methods		O	literature review
	5.9	usage of realistic examples and exercises	from organisation or practice	E	literature review
	5.10	including reflection/feedback on methods and their application in training	as commentary function with reflective questions	O	conclusion of analysis
	5.11	reflection includes benefits, results and time needed		O	conclusion of analysis
	5.12	combining method access in method portal with training		O	conclusion of analysis
	5.13	considering different types of learners and knowledge levels	different media	E	conclusion of analysis
5. training and learning methods for practice	5.14	consideration of organisation's needs		E	literature review
	5.15	planning of implementation		E	literature review
	5.16	multidisciplinary change teams		O	literature review
	5.17	top management support		E	literature review
	5.18	method champions (experts)		O	literature review
	5.19	identifying real tasks for method trainings prior to training	prepare training accordingly	O	conclusion of analysis

	5.20	identifying organisation's needs prior to training	within separate workshop or interview with core team	E	conclusion of analysis
	5.21	including workshop before and after training for top management, multidisciplinary change team and method expert to plan implementation	planning training and further utilisation of methods, e.g. using checklists	E	conclusion of analysis
5. training and learning methods for design education	5.22	using projects or other types of teamwork for method application	teamwork	E	conclusion of analysis
	5.23	attraction and motivation through entertaining formats and media	modern media	O	conclusion of analysis
	5.24	attraction and motivation through diversification of courses	media changes	O	conclusion of analysis

B1 – List of barriers, success factors and requirements for method knowledge transfer (from literature)

cluster		success factors and barriers	authors	requirements
presentation of methods	barriers	too theoretical, too abstract	Araujo, 2001; Andreasen, 2003; Jänsch, 2007	
		presented in a "strange" kind of language	Araujo, 2001; Andreasen, 2003	
		complex presentation	Beckmann, 2014; Beckmann, 2016	
		incomplete	Beckmann, 2014; Beckmann, 2016	
		no uniform structure	Beckmann, 2014; Beckmann, 2016	
		prototype software tools	Beckmann, 2014; Beckmann, 2016	
		poor information on method / lack of clear instruction	Araujo, 2001; Andreasen, 2003	
	success factors	simple fitting methods	Beckmann, 2014; Beckmann, 2016	simple methods
		keep design methods simple	Birkhofer et al., 2005	
		reduced complexity but not too simple/far from reality	Badke-Schaub, 1994	simple representation of methods
		teach aims, objectives, principles, skills	Beckmann, 2014; Beckmann, 2016	focus on essential
		goal clear and explained	Badke-Schaub, 1994	
		focus on meain task	Beckmann, 2014; Beckmann, 2016	
		only provide specific and relevant knowledge	Beckmann, 2014; Beckmann, 2016	
		perceived performance	Lohmeyer et al., 2014	focus on results
		focus on methods for best processes	Birkhofer et al., 2005	
		methods of to have processbale results	Birkhofer et al., 2005	
		consideration of different knowledge levels	Schmidt-Kretschmer & Budych, 2009	consideration of different knowledge levels
		orientation on existing knowledge	Jänsch et al., 2006	
		consider user (novices and experts)	Lutters et al., 2014	
		meet the designer	Birkhofer et al., 2005	
		improvement, update and evaluation of methods	Beckmann, 2014; Beckmann, 2016	improvement, update and evaluation of methods
		software supported approaches (one database)	Birkhofer et al., 2005	software supported approaches (one database)
implementation and support (in organisation)	barriers	difficult to implement	Araujo, 2001; Andreasen, 2003	
		missing time for method use, tight project time scale, effort	Beckmann, 2014; Beckmann, 2016	
		difficult to use	Araujo, 2001; Andreasen, 2003	
		lack of necessary tool use skills in company	Araujo, 2001; Andreasen, 2003; Beckmann, 2014; Beckmann, 2016	
		lack of management support and capacity	Beckmann, 2014; Beckmann, 2016	
		wrong team composition	Schneider et al., 2006	
		lack of investigations into fitness, usefullness and benefits	Araujo, 2001; Andreasen, 2003	
		too high expenses	Schneider et al., 2006	
		too fast, too far reaching, too frequent changes	Beckmann, 2014; Beckmann, 2016	
		overcoming old work practice	Beckmann, 2014; Beckmann, 2016	
		teaching problems, lack of support	Beckmann, 2014; Beckmann, 2016	
		substantial relearning is difficult	Beckmann, 2014; Beckmann, 2016	

cluster		success factors and barriers	authors	requirements
implementation and support (in organisation)	success factors	understanding company needs	Beckmann, 2014; Beckmann, 2016	consideration of organisation's needs
		anchoring in organisation	Beckmann, 2014; Beckmann, 2016	
		don't forget organisation	Birkhofer et al., 2005	
		needs and aims clarified	Beckmann, 2014; Beckmann, 2016	
		reusable and extendible methods	Lohmeyer et al., 2014	reusable and extendible methods
		planning of change process/impacts	Beckmann, 2014; Beckmann, 2016	planning of implementation
		monitore implementation, include feedback	Beckmann, 2014; Beckmann, 2016	
		long-term collaboration	Beckmann, 2014; Beckmann, 2016	
		planning of implementation	Beckmann, 2014; Beckmann, 2016	
		interdisciplinary change teams	Beckmann, 2014; Beckmann, 2016	interdisciplinary change teams
		pilot projects	Beckmann, 2014; Beckmann, 2016	pilot projects or/and usage of real design tasks
		deal with current design	Birkhofer et al., 2005	
		meet design situation	Birkhofer et al., 2005	
		realistic actions	Jänsch et al., 2006	
		top management support	Beckmann, 2014; Beckmann, 2016	top management support
		method champions (experts)	Beckmann, 2014; Beckmann, 2016	method champions (experts)
		help with exercises	Schmidt-Kretschmer & Budych, 2009	training and provision of support
		dialogue to an expert	Jänsch et al., 2006	
		training and providing support	Beckmann, 2014; Beckmann, 2016	
acceptance of methods	barriers	applicability and practical relevance	Beckmann, 2014; Beckmann, 2016	
		negative acceptance	Araujo, 2001; Andreasen, 2003	
		fear of economisation, job loss or additional liabilities	Beckmann, 2014; Beckmann, 2016	
		advantages of methods not recognised	Beckmann, 2014; Beckmann, 2016	
		no evaluation of results attained by methods	Araujo, 2001; Andreasen, 2003	
		delayed benefits vs. time pressure	Beckmann, 2014; Beckmann, 2016	
		mediate regress within ramp-up phase	Beckmann, 2014; Beckmann, 2016	
	success factors	involve designers in decision on method	Lutters et al., 2014	involvement of designers in method selection
		versatile engineers --> adapt formats	Lutters et al., 2014	
		convincing people	Beckmann, 2014; Beckmann, 2016	
		reflection questions	Jänsch et al., 2006	provision of reflection and experience exchange possibilities
		get on with methods and talk about experiences	Birkhofer et al., 2005	
		reflection on action	Badke-Schaub, 1994	
		applicable intuitively	Lohmeyer et al., 2014	offer training/action possibilities
		teach theory but train methods	Birkhofer et al., 2005	
		teach- and learnable	Lohmeyer et al., 2014	
		offer action possibilities	Jänsch et al., 2006	
		monetary benefit-cost ratio	Lohmeyer et al., 2014	fast transparent benefits
		mediate and quantify benefits	Beckmann, 2014; Beckmann, 2016	
		quick realisation	Beckmann, 2014; Beckmann, 2016	quick results and time saving through methods
		time, endurance and continuing attendance	Beckmann, 2014; Beckmann, 2016	
		staggered introduction	Beckmann, 2014; Beckmann, 2016	
consideration of daily work	barriers	high effort to adapt methods	Jänsch, 2007	
		low flexibility	Jänsch, 2007	
		not adapted to individual designer	Beckmann, 2014; Beckmann, 2016	
		distance to daily work problems	Jänsch, 2007	
		too complicated to understand	Araujo, 2001; Andreasen, 2003	
	success factors	adapt methods	Beckmann, 2014; Beckmann, 2016	provision of adaptable/ modular methods
		flexible and adaptable	Lohmeyer et al., 2014	
		adapt organisation vs. adapt methods	Beckmann, 2014; Beckmann, 2016	
		examples from daily work	Schmidt-Kretschmer & Budych, 2009; Badke-Schaub, 1994	usage of realistic examples and exercises (from organisation)
		unsolved problems	Schmidt-Kretschmer & Budych, 2009	
		complex, realistic task	Jänsch et al., 2006	
		exercises	Schmidt-Kretschmer & Budych, 2009	
		motivation by presenting problems, pictures, etc.	Badke-Schaub, 1994	

B2 – Overview of existing method knowledge trainings and transfer approaches

author	name of concept	description or type of concept	media and formats used	DE	P
Ahmad et al. (2014)	DG-MOTS (Design Game Matrix of Tool Selection)	Snakes and Ladders game as basis: selecting a good method/tool allows the designer to skip design steps, while a poor selection requires them to restart several steps, from preparatory phase to detailed design phase	game	x	
Albers, Walter et al. (2014), Reiss, Bursac et	InnoFox	mobile application within industrial workshops, mainly used to select suitable methods, also testes in student groups	mobile application, workshop	(x)	x
e.g.,Albers et al. (2000), Albers et al. (2004)	KaLeP (Karlsruher Lehrmodell für Produktentwicklung)	case-based learning using lectures, tutorials and workshops/projects even for big groups (>500 students) or in virtual environments (ProVIL), co-creation with industry partners that provide design tasks for the students	projects, virtual teamwork, feedback from experts (industry partners and research assistents)	x	
Beckmann et al. (2016)	Approach to Transfer Methods for Developing Modular Product Families into Practice	description and preparation of new design method using the MPV (Method and Process Visualisation), determination of needed methodical support in organisation, planning of method integration (selection and adaption), roll-out with training	computer-based method description for presentation/selection (MPV), transfer concept		x
Birkhofer, Lindemann et al. (2001)	thekey Process	definition of elements, content and roles within the design eductaion with the help of portals (CiDaD, pinngate, etc.)	training concept	x	
Braun (2005)	Supporting Matrix	matrix for companies to identify support needs on objectives, procedure, task and method level	checklist matrix		x
Braun and Lindemann	Munich Model of Methods	clarification of method application, method selection, method adaption, method application	transfer concept		x
Bucciarelli (1997)	Delta Design Game	players are assigned one of four roles and form teams to design a new residence suitable for inhabitants of the imaginary Deltoid plane	game	x	
Geis, Bierhals et al. (2008)	Method transfer model	four pillars: simplification of methods, adaption of methods, promotion of methods and training of methods	transfer concept		x
Geis, Birkhofer et al. (2008), Geis (2011)	BEMAP (Behavioral Marker in der Produktentwicklung)	training setup: knowledeg transfer via advanced organizer and presentation, basic exercise (exercise and feedback), advanced exercise (exercise and feedback)	training concept	x	(x)
Geis and Birkhofer (2009), Geis (2011)	Checklist for reflection	checklist for self-reflection of methodical procedure containing expert knowledge, selection of methods, adaptions of methods, execution of methods and reflection-on-action	checklist		x
Geis (2011)	SAM model (Modell des situationsangepassten Methodeneinsatzes)	model for method application based on the situation, basis for the above-mentioned checklist for reflection by Geis and Birkhofer	transfer concept	x	x
Jänsch	Checklist for training elements	checklist containing advices on the arrangement of traning elements (content, exercises, environment, trainer, tools, method descriptions, examples, structure and course) for design education	checklist	x	
Lenhart	User Classification	classification of presentation and amount of information given for different expertise levels, mainly text-based, also picture integration as well as navigation options	documents (text, pictures), navigation	x	x
Reiss, Albers et al. (2017)	SPALTEN game	learning game to learn and experience the SPALTEN problem solving method and design methods, developed to apply within workshops in small groups after learning the theory of SPALTEN	board-game in workshop	x	x
Reiss, Bavendiek et al.	Method videos	video tutorials decribing how a method works using an exemplary design situation	video	x	
Weiß (2006), Weiß and Birkhofer (2006)	Project Guide (as part of pinngate)	configurator of workshop content based on the portal pinngate, usable for workshop preparation and training	method portal for preparation and training	x	x

B3 - Mapping of requirements on method knowledge transfer and media and formats

		media and formats									
		primer focus on method provision					primer focus on method application				
		documents consisting of text and pictures	checklist	video	method portal, (digital) method description	mobile application	game	virtual team workshop	workshop, training	projects	feedback and reflection
requirements: presentation of methods	simple representation of methods	simple descriptions with few sentences including a revelant picture on procedure	simple step-by-step checklist	short explanation video demonstrating method application	simple descriptions with few sentences including a revelant picture on procedure and further information	simple descriptions with few sentences including a revelant picture on procedure and further information	simple descriptions with few sentences including a revelant picture on procedure	if possible, demonstration of method, variants needed if necessary	demonstration of method	additional media or formats necessary	n.a.
	simple methods	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	focus on essential	similar to simple representation	similar to simple representation	similar to simple representation	similar to simple representation	similar to simple representation	similar to simple representation	similar to simple representation	similar to simple representation	additional media or formats necessary	n.a.
	focus on results	naming results explicitly, showing way to results	naming results explicitly in checklist, provide steps to reach results	naming results explicitly, showing way to results	naming results explicitly, showing way to results	naming results explicitly, showing way to results	naming results explicitly, showing way to results	naming results explicitly, showing way to results	naming results explicitly, showing way to results	additional media or formats necessary	n.a.
	consideration of different knowledge levels	provision of different versions for different knowledge levels	provision of different versions for different knowledge levels	great effort to provide different versions for different knowledge levels	provision of different versions for different knowledge levels	provision of different versions for different knowledge levels	great effort to provide different versions for different knowledge levels	using knowledge differences within workshop for heterogeneous teams	using knowledge differences within workshop for heterogeneous teams	using knowledge differences within projects for heterogeneous teams	feedback depending on experience possible
	improvement, update and evaluation of methods	continuous improvement of documents	continuous improvement and adaptions to situation	hard to improve content of video without great effort	continuous improvement of descriptions	continuous improvement of descriptions	hard to improve content of video without great effort	n.a.	n.a.	n.a.	per se fulfilled
	software supported approaches (one database)	hard to implement, advices possible	hard to implement, advices possible	hard to implement, advices possible	easy to implement, links or advices possible	easy to implement, links or advices possible	software-based games possible, but connection to tools on methods hard	easy to send links or advices to partici-pants, special soft-ware trainings possible	special software trainings possible	easy to implement software into projects	n.a.
requirements: implementation and support (in organisation)	consideration of organisation's needs	adaption to organisation standards, processes and products	adaption to organisation standards, processes and products	adaption to organisation standards, processes and products	adaption to organisation standards, processes and products	adaption to organisation standards, processes and products	adaption to organisation standards, processes and products	special workshop for identifying organisation's needs	special workshop for identifying organisation's needs	special project to generate adaptions to organisation's needs	using feedback and reflection for adaptions to organisation
	reusable and extendible methods	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	planning of implementation	hard to implement, advices possible	special checklist for implementation	hard to implement, advices possible	hard to implement, advices possible	hard to implement, advices possible	special game on implementation process	special workshop on implementation process	special workshop on implementation process	special (pilot) project on implementation process	using feedback and reflection to improve implementation process
	interdisciplinary change teams	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	special workshop for change team	special project for change team	n.a.
	pilot projects or/and usage of real design tasks	n.a.	n.a.	n.a.	n.a.	n.a.	hard to use realistic (complex) situations	method application on real task possible	method application on real task possible	method application on task of pilot project possible	n.a.
	top management support	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	special workshop for top management	special (pilot) project for top management	n.a.
	method champions (experts)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	special workshop for method champions	special (pilot) project for method champions	n.a.
	training and provision of support	n.a.	n.a.	n.a.	n.a.	n.a.	application of methods possible	application of methods possible	per se fulfilled	application of methods possible	n.a.

			media and formats									
			primer focus on method provision					primer focus on method application				
			documents consisting of text and pictures	checklist	video	method portal, (digital) method description	mobile application	game	virtual team workshop	workshop, training	projects	feedback and reflection
requirements	acceptance of methods	involvement of designers in method selection	n.a.	checklist providing method alternatives	n.a.	via method access selection possibilities	via method access selection possibilities	via game logic selection possibilities	proposition of alternative methods to select	proposition of alternative methods to select	proposition of alternative methods to select	reflection on method selection possible, involvement only retrospective
		provision of reflection and experience exchange possibilities	implentation of reflection questions	reflection questions/ checklist	implentation of reflection questions	commentary function, reflection questions	commentary function, reflection questions	implentation of reflection questions	moderator asking for feedback or experience exchange	moderator asking for feedback or experience exchange	discussion among team members leads to experience exchange	per se fulfilled
		offer training/action possibilities	provision of exercises	checklist offering actions depending on input	only demonstrating action possibilities	provision of exercises	provision of exercises	as part of the game	as part of the virtual workshop	as part of the workshop	per se fulfilled	n.a.
		fast transparent benefits	n.a.	n.a.	n.a.	n.a.	n.a.	can be shown within an exemplary application	can be shown within an exemplary application or on a real task	can be shown within an exemplary application or on a real task	can be shown within projects	n.a.
		quick results and time saving through methods	n.a.	n.a.	n.a.	n.a.	n.a.	no realistic situation, hard to show	no real situation (moderator present), hard to show	no real situation (moderator present), hard to show	can be shown within projects if compa-rabile project without methods is available	n.a.
	conside-ration of daily work	provision of adaptable/ modular methods	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
		usage of realistic examples and exercises (from organisation)	provision of practical examples	n.a.	using practical examples for demonstration	provision of practical examples	provision of practical examples	hard to use realistic (complex) situations	method application on real task possible	method application on real task possible	method application on task of project possible	n.a.

C1 – Results of the sensibily analysis from method user characteristics to methods

Team characterstics and competencies

	team's properties and characteristics	discussion in a group	benchmark	documentation of requirements	persona	literature and patent research	QFD	brainstorming	gallery method	method 635 (brainwriting)	synectics	Morphological Analysis	cost utility analysis	FMEA	point rating system	Ø
		methods														
		sensitivity regarding methods														
team characteristics	team size*	4	1	1	2	2	3	3	3	4	3	1	3	2	2	3,4
	multidisciplinarity	4	1	3	4	1	3	3	3	3	3	2	3	2	2	3,6
	hierarchical differences	3	2	2	3	0	2	3	2	1	3	2	2	2	2	3,1
	age	?														0,0
	gender	3	1	1	2	0	0	3	1	1	2	1	1	1	1	2,3
	cultural differences	3	2	1	3	3	3	3	2	0	2	2	2	2	2	3,1
	roles within team*	3	1	2	2	1	2	3	2	2	3	2	1	1	1	2,9
	value system	2	?	?	2	?	1	2	?	?	1	?	?	?	?	0,9
	motivation*	3	2	2	3	2	3	3	3	3	3	2	2	2	2	3,5
	autonomy of team	1	1	2	0	2	1	0	0	0	0	0	2	2	2	1,9
competencies	professional competence (abstraction ability*, qualification*)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4,0
	social competence (communication skills within team*)	3	2	1	4	1	2	3	2	1	3	2	1	2	1	3,0
	methodological competence	1	3	2	1	2	3	2	2	2	2	2	3	3	2	3,1
	self competence	2	1	2	1	3	3	1	3	3	1	2	3	3	2	3,1
	experience with method usage*	1	3	2	2	2	3	1	2	2	4	1	2	3	1	3,1

Collaboration characteristics

team's properties and characteristics		discussion in a group	benchmark	documentation of requirements	persona	literature and patent research	QFD	brainstorming	gallery method	method 635 (brainwriting)	synectics	Morphological Analysis	cost utility analysis	FMEA	point rating system	Ø
		sensitivity regarding methods														
collaboration characteristics	number of partners	see team size														0,0
	location															3,4
	time															3,4
	language															3,6
	organisation															2,4
	size of company															2,7
	intensity of collaboration															2,3
	distribution of components															1,6
	distribution of tasks															1,1
	number of interfaces															2,5
	data access															2,4
	competence	see more detailed competencies														0,0
	capacity															2,5
	tool compatibility															2,1
	compatibility of methods	?														0,0

Remarks: Team characterstics and competencies

team's properties and characteristics		remarks regarding evaluation	references	example	optimum	diagnose
team characteristics	team size*	depending on method/task; in general 3 to 6 persons optimal; maximal 10 or use of special big group methods (e.g., for workshops)	Hoegl (2005), Strasser (2004), Weiss and Hoegl (2016), Kauffeld (2001)	Brainstorming: optimal team size (5-7) Method 635: 6 persons	inconsistent	simple enquery
	multidisciplinarity	stimulates creativity; slows down decision making; depending also on team size and if discussions are necessary; diversity correlates possitivly to task performance except for straight forward tasks, routine tasks can lead to conflicts	Higgs et al. (2005), Yong et al. (2014)	Brainstorming: good heterogeneity from different fields with different views point rating system: heterogeneity for different knowledge, but as the method is quasi-objective, not such a big influence	balanced	self-evaluation
	hierarchical differences	too high hierarchical differences within the team can block the flow of ideas and hinder rather shy persons to contribute something; important for decision and discussion; considering power distance cultural dimension of Hofstede	Hofstede (1983), Hofstede et al. (2010)	discussion in a group: important literature and patent research: no influence as in general method for individuals	minimize	simple enquery
	age	no direct correlation to age, better rated as experience or personal motivation	Joshi and Roh (2009)	?	no statement	-
	gender	the gender can influence the dynamic of groups; thus, it might be relevant for discussion situations	Joshi and Roh (2009)	discussion in a group: more important with bigger teams literature and patent research: no influence as in general method for individuals	balanced	-
	cultural differences	cultural differences can open the mind of a team for new ideas and other views; slow down decision making; provide opportunities for analysis methods	Hofstede (1983), Hofstede et al. (2010), Hall (1976)	persona: different cultural backgrounds may lead to more divers personas method 635: as no direct interaction is needed, there should be no or few influences	no statement	self-evaluation
	roles within team*	depending on task and on method (e.g. a moderator), but also connected to hierarchical differences; direct correlation to methods is difficult	Belbin (1993)	benchmark: low influence brainstorming: important to provide a good moderator	balanced	-
	value system	only relevant if there is a stronger expression of individuals in a team (discussion) or in regard to the customer (requirements); connected to cultural differences; mental models are stressed as important	Lohmeyer (2013), Araujo, JR (2001), Nerdinger et al. (2014)	persona: different value systems can result in very different personas, similar value systems reduce probably the span of results benchmark: the influence of the value system on the results of a benchmark may vary, thus there is no clear statement on the influence possible	no statement	-
	motivation*	in general, a high motivation is very important, for team methods it is more important to motivate the others as well; if sceptics are part of the team, it is important to gain their acceptance or motivation for the method application	Ponn (2007)	synectics: the influence is high; if a team member is highly motivated he/she can stimulate others benchmark: if applied individually, there is a lower influence	maximize	-
	autonomy of team	a stronger autonomy stimulates the innovative potential of a team; a direct correlation to methods is low, as it is more seen in the entire process not only for tasks; on task basis low autonomy influences decision making more than ideation	Kauffeld (2006), Hertel et al. (2006)	documentation of requirements: there is in general a strong dependencies from other domains/departments gallery method: within the method application the autonomy plays no role	maximize	-
competencies	professional competence (abstraction ability*, qualification*)	plays always a role; more professional competence in a team can lead to qualitative better results, lower professional competence maybe to more ideas and new views	Kauffeld (2001), Kauffeld (2006), Badke-Schaub and Frankenberger (2004)	point rating system: experts from different domains with high professional competence are preferable, non-experts could reduce the method result's quality gallery method: a mixture of experts and non-experts is preferable, too many experts or too many non-experts can reduce the method result's quality	maximize	C.R.I.
	social competence (communication skills within team*)	the differentiation between funcional and disfunctional social competence has to be considered; disfunctional social competence is important in bigger teams (e.g., killer phrases or conflict management); also important for decision making in a team	Kauffeld (2001), Kauffeld (2006), Badke-Schaub and Frankenberger (2004)	persona: low social competence can hinder the process to define personas in a team method 635: as no direct interaction is needed, there should be no or few influences	balanced	C.R.I.
	methodological competence	important for complex methods and tools to reduce the effort to learn and apply (new) methods	Kauffeld (2001), Kauffeld (2006), Badke-Schaub and Frankenberger (2004)	QFD: high influence as a low methodological competence in a team can hinder the correct application from each team member brainstorming: if a moderator is provided, this competence is not very relevant compared to others	maximize	C.R.I.
	self competence	important for individual work, for decision making and goal definition	Kauffeld (2001), Kauffeld (2006), Badke-Schaub and Frankenberger (2004)	literature and patent research: high influence as method user has to work individually and has to manage time and tasks on his/her own brainstorming: if a moderator is provided, this competence is not very relevant compared to others	maximize	C.R.I.
	experience with method usage*	for more complex methods, a higher experience with other methods is preferable to be less frustrating	Badke-Schaub and Frankenberger (2004), Braun (2005), Strasser (2004)	brainstorming: as it is easy to apply, almost everyone can be part of a brainstorming session synectics: as the method is complex and needs some experience, the experience with other methods might be helpful for the team	maximize	self-evaluation

Remarks: Collaboration characteristics

collaboration characteristics	number of partners	-	Gaul (2001), Anderl et al. (1999), MacGregor (2002)	-	-	-
	location	important for team methods in which direct interaction is required; face-to-face communication is assumed to be different to virtual communication, thus, the location is important for the method application	Kauffeld et al. (2016), Chamakiotis (2010), Gaul (2001), Anderl et al. (1999), MacGregor (2002), Schulze et al. (2017)	method 635: as the results of one participant build on the others' results, the location is relevant for the method application cost utility analysis: the results can be exchanged digitally, thus, the influence of the location is lower	minimize	simple enquery
	time	important for team methods in which direct interaction is required	Kauffeld et al. (2016), Chamakiotis (2010), , Gaul (2001), Anderl et al. (1999), MacGregor (2002), Schulze et al. (2017)	method 635: as the results of one participant build on the others' results, the application of the method at the same time is required cost utility analysis: the results can be exchanged digitally, thus, the influence of the time is less important; eventually a sequential work is possible	minimize	simple enquery
	language	important for methods with discussions or written exchange of information; one common language is required to properly apply a method together	Kauffeld et al. (2016), MacGregor (2002), Beetham and Sharpe (2008)	literature and patent research: further languages provide further sources method 635: as no direct interaction is needed, there should be no or few influences	minimize	simple enquery
	organisation	belonging to the same organisation enables an easier exchange of information; the possibility to meet each other for discussions is in general easier	Gaul (2001), Anderl et al. (1999), MacGregor (2002)	documentation of requirements: there is a low influence, the creation of requirement lists over organisation boundaries might result in problems regarding know-how and tools brainstorming: the influence is medium, as beside the know-how also the effort to meet is an influence factor	minimize	-
	size of company	important for team methods in which multiple persons are involved	Gaul (2001), Anderl et al. (1999)	brainstorming: in a small enterprise in which only one to two persons work in the development team, the application of a team method with multiple persons is difficult, whereas in a bigger company it is easier to apply a method with multiple persons point rating system: as possible individual method it can be applied in small and big enterprises; the availability of experts might play a role	balanced	-
	intensity of collaboration	more important for goal definition and exchange of information due to potential know-how exchange; can be influenced by the personal motivation of each team member	Gaul (2001), Anderl et al. (1999), MacGregor (2002)	benchmark: low to medium influence, an intense collaboration allows probably an easier exchange of relevant information regarding the concurrence gallery method: low influence, maybe ideas will not be provided openly	maximize	-
	distribution of components	the application of methods with a distribution of components does not have a high influence, only the experience with components may lead to slightly different results in ideation and decision making; a method application can set the structure and the framework for a good collaboration within this more complex situation	Gaul (2001), Anderl et al. (1999), MacGregor (2002)	benchmark: no influence point rating system: with other knowledge on different components the results may differ	minimize	-
	distribution of tasks	if the tasks are distributed, the same restrictions as time and location may appear, no direct influence to the distribution of tasks; a method application can set the structure and the framework for a good collaboration within this more complex situation	Gaul (2001), Anderl et al. (1999), MacGregor (2002)	-	minimize	-
	number of interfaces	important for ideation and goal definition or documentation; a method application can set the structure and the framework for a good collaboration within this more complex situation	Gaul (2001), Anderl et al. (1999), MacGregor (2002)	documentation of requirements: more interfaces result in more requirements and make thus the method more complex discussion in a group: the number of interfaces has only an indirect influence on the method application, the expertise of participants is relevant, not the number of interfaces	minimize	-
	data access	important for methods with data exchange or information exchange; a method application can set the structure and the framework for a good collaboration within this more complex situation	Gaul (2001), Anderl et al. (1999)	documentation of requirements: the provision of requirements for partners without data access is possible, but requires additional work or additional solutions synectics: in a synectics session all necessary information should be provided, further data is not required	maximize	-
	competence	-	Kauffeld (2001), Kauffeld (2006), Badke-Schaub and Frankenberger (2004), MacGregor (2002), Gaul (2001), Anderl et al. (1999)	-	-	-
	capacity	important in general but especially for time consuming methods	Gaul (2001), Anderl et al. (1999)	literature and patent research: more capacity allows more focus on a literature and patent research point rating system: as it is a simple, not very time and personal resources consuming method, the influence of the capacity of the method user is low	maximize	-
	tool compatibility	important for methods with data exchange or information exchange, similar to data access	Gaul (2001), Anderl et al. (1999), MacGregor (2002)	QFD: with same tools, the results can be taken up and be completed brainstorming: as normally no tools are needed, there is no influence of the tool compatibility	maximize	-
	compatibility of methods	no sensible correlation when the results of methods applied are mapped to other methods; no statement on the collaboration	Gaul (2001), Anderl et al. (1999)	-	-	-

C2 – Calculation and values for the assessment of the Competence-Reflection-Inventory

	professional	social	methodological	self
M	73,14	70,73	70,73	74,3
SD	18	19,71	20,65	18,82
M-SD	55,14	51,02	50,08	55,48
M+SD	91,14	90,44	91,38	93,12
alpha	0,95	0,95	0,95	0,95
alpha/2	0,475	0,475	0,475	0,475
Z	1,96	1,96	1,96	1,96
n	561	561	561	561
Zalpha/2*SD/root(n)	1,49	1,63	1,71	1,56
lower CI	71,65	69,10	69,02	72,74
upper CI	74,63	72,36	72,44	75,86
below average	<55	<51	<50	<55
below average to average	55-70	51-68	50-68	55-71
average	71-75	69-73	69-73	72-76
average to above average	76-91	74-90	74-91	77-93
above average	>91	>90	>91	>93

C3 – Adaptions and hints for selected methods in locally distributed teams

method	hints for virtual teams
discussion in a group	for locally distributed application use video conferencing
	a moderator should be used that is very familiar in the common language
	sensitize team members to cultural differences and use them as an advantage
benchmark	division into areas to be analyzed (companies, market segments, countries, ...)
	use different languages and cultures for contact and understanding
documentation of requirements	access to requirement list for all team members
	enter contacts for queries with every requirement
	set a language for the requirement list
requirements from an analysis of lifecycle phases	access to requirement list for all team members
	division for sequential processing: assignment of the lifecycle phases to the respective experts
persona	for locally distributed application use video conferencing
	sensitize team members to cultural differences and use them as an advantage
literature and patent research	access to search results for all team members
	communication media necessary for collusion
QFD	division for sequential processing: filling in individual areas of the HoQ
	set a language for the documentation
	tools for communication and exchange of results necessary
weak point analysis	access to documentation of the weak point analysis for all team members
	division of the steps of the procedure or areas to be considered
WH-questions	answering the questions in individual work, merging and evaluating the results by method experts
	each answers the questions in his own language, then, if necessary, translation of the answers
brainstorming	for locally distributed application use video conferencing
	a moderator should be used that is very familiar in the common language
	sensitize team members to cultural differences and use them as an advantage
gallery method	for locally distributed application use video conferencing
	create digital sketches and use desktop sharing to present the ideas within the "gallery"
	if paper-based sketches are used, make sure the quality of your camera and internet connection is good enough to share your results
method 635 (brainwriting)	for locally distributed application use a digital template and create digital sketches that are shared via a cloud or sent via mail to the next person
	for locally distributed application accompanying video conferencing assists the structured method application
	plan some more time for the exchange of ideas to the next person
synectics	for locally distributed application use video conferencing
	a moderator should be used that is very familiar in the common language
	sensitize team members to cultural differences and use them as an advantage
Morphological Analysis	set a language for the Morphological Box
	tools for communication and exchange of results necessary
	access to the Morphological Box for all team members recommended
	defining sub tasks together, dividing sub solutions individually and collect results via desktop-sharing
cost utility analysis	access to documentation of the cost utility analysis for all team members or using desktop sharing, if parallel discussion of evaluations
	tools for communication and discussion of evaluations necessary
FMEA	access to FMEA file for all team members or using desktop sharing, if parallel discussion
	tools for communication and discussion necessary
point rating system	access to documentation of the point rating system for all team members or using desktop sharing, if parallel discussion of evaluations
	tools for communication and discussion of evaluations necessary

C4 - Matrix for assigning values for team / user specific attributes to selected methods

			methods													
			discussion in a group	benchmark	documentation of requirements	persona	literature and patent research	QFD	brainstorming	gallery method	method 635 (brainwriting)	synectics	morphological analysis	cost utility analysis	FMEA	point rating system
team/user attributes	team size	1	✗	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓	!	✓
		2-3	!	✓	✓	✓	✓	✓	!	!	✗	!	✓	✓	✓	✓
		4-6	✓	✓	✓	✓	✓	!	✓	✓	✓	✓	✓	✓	✓	✓
		7+	✓	!	!	✗	!	✗	✓	✓	!	✗	✗	✗	✗	✗
	multi-disciplinarity	heterogeneous	!	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗
		balanced	✓	✓	✓	!	✓	✓	!	!	!	!	!	✓	!	✓
		homogeneous	✗	!	!	✗	!	!	✗	✗	✗	✗	✗	✓	✓	✓
	hierarchical differences	yes	!	✓	✓	✗	✓	✓	✗	✗	✓	✗	!	✓	!	✗
		no	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	cultures	same	✓	✓	✓	!	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		similar	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		different	✓	!	!	✓	✓	!	!	!	✓	!	!	!	!	!
	professional competence	below Ø	!	✗	✗	✓	!	!	✗	✗	✗	✗	✗	✗	✗	✗
		below Ø to Ø	✓	!	!	✓	✓	✓	!	✗	✗	!	✗	✗	✗	✗
		Ø	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	✓	✗	✓
		Ø to above Ø	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		above Ø	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	social competence	below Ø	✗	✗	✓	✗	✓	✗	✗	✗	✓	✗	!	✗	✗	!
		below Ø to Ø	✗	!	✓	✗	✓	✗	✗	✗	✓	✗	✓	!	!	!
		Ø	✗	✓	✓	!	✓	✓	!	✓	✓	!	✓	✓	✓	✓
		Ø to above Ø	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		above Ø	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	methodological competence	below Ø	!	✗	✗	✗	✗	✗	✗	✗	✗	✗	!	✗	✗	!
		below Ø to Ø	!	!	✗	!	✗	✗	!	✗	✓	!	✓	!	✗	✓
		Ø	✓	✓	✓	✓	!	!	✓	✓	✓	✓	✓	✓	✓	✓
		Ø to above Ø	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		above Ø	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	self competence	below Ø	✗	✗	✗	✗	!	✗	✗	✗	✗	✗	!	✗	✗	!
		below Ø to Ø	✗	!	✗	!	✓	✗	✗	✗	✗	✗	✓	✗	✗	✓
		Ø	✓	✓	!	✓	✓	!	✓	✓	✓	!	✓	✓	!	✓
		Ø to above Ø	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		above Ø	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	method experience	beginner	✓	✗	✓	✓	✓	✗	✓	✓	✓	✗	✓	✗	✗	✓
		advanced	✓	✓	✓	✓	✓	✓	✓	✓	✓	!	✓	✓	✓	✓
		expert	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	local distribution	distributed rooms	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		distributed locations	!	✓	✓	!	✓	!	!	!	!	!	!	!	!	!
		distributed countries	!	✓	✓	!	✓	!	!	!	!	!	!	!	!	!
	temporal distribution	parallel	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		mixed	!	✓	✓	!	✓	!	!	!	!	!	!	!	!	!
		sequential	✗	✓	✓	✗	✓	!	✗	✗	✗	✗	!	!	!	!
	language	same	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		one common language	!	✓	✓	✓	✓	✓	!	✓	✓	!	✓	✓	✓	✓
		different	✗	✗	✗	!	!	✗	✗	✗	✗	✗	!	✗	✗	✗

C5 – Pairwise comparison to determine the weights w_c of attributes for method access via relevance filter

attribute	required time	complexity of upcoming task	process phase	team size	multidisciplinarity	hierarchical differences	culture	method experience	professional competence	social competence	method competence	self competence	local distribution	temporal distribution	language	sum	weight
required time	1	0	2	1	2	1	2	0	0	2	2	2	0	0	2	17	7,6
complexity of upcoming task	2	1	1	1	1	1	2	0	0	1	1	1	1	1	2	16	7,1
process phase	0	1	1	0	2	2	2	1	0	0	0	0	1	1	2	13	5,8
team size	1	1	2	1	2	1	2	1	1	1	1	1	1	1	1	18	8,0
multidisciplinarity	0	1	0	0	1	1	1	1	1	1	1	1	1	1	1	12	5,3
hierarchical differences	1	1	0	1	1	1	2	1	1	1	1	1	1	1	2	16	7,1
culture	0	0	0	0	1	0	1	0	0	1	0	1	1	1	1	7	3,1
method experience	2	2	1	1	1	1	2	1	1	2	1	1	1	1	2	20	8,9
professional competence	2	2	2	1	1	1	2	1	1	2	1	1	1	1	2	21	9,3
social competence	0	1	2	1	1	1	1	0	0	1	0	1	0	0	1	10	4,4
method competence	0	1	2	1	1	1	2	1	1	2	1	1	0	0	0	14	6,2
self competence	0	1	2	1	1	1	1	1	1	1	1	1	0	0	0	12	5,3
local distribution	2	1	1	1	1	1	1	1	1	2	2	2	1	1	1	19	8,4
temporal distribution	2	1	1	1	1	1	1	1	1	2	2	2	1	1	1	19	8,4
language	0	0	0	1	1	0	1	0	0	1	2	2	1	1	1	11	4,9
															sum	225	

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Bavendiek, A.-K., Huth, T., Inkermann, D., Paulsen, H., Vietor, T. & Kauffeld, S. (2018). "Collaborative Design: Linking Methods, Communication Tools and Competencies to Processes", Proceedings of DESIGN 2018.

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